BOFECILLOS MOUNTAINS

A NATURAL AREA SURVEY
NO. 12

Lyndon B. Johnson School of Public Affairs
The University of Texas at Austin
1976

The full-color frontispiece is by photographer Reagan Bradshaw and represents but a small part of the work he recorded in the course of the Bofecillos Mountains area survey. Transparencies of his photos of this and other survey areas have been filed with the Natural Areas Survey project, Lyndon B. Johnson School of Public Affairs, The University of Texas at Austin. Mr. Bradshaw is one of the finest nature photographers of the Southwest. His work on these natural areas is sure to increase public awareness of the need to save and protect.

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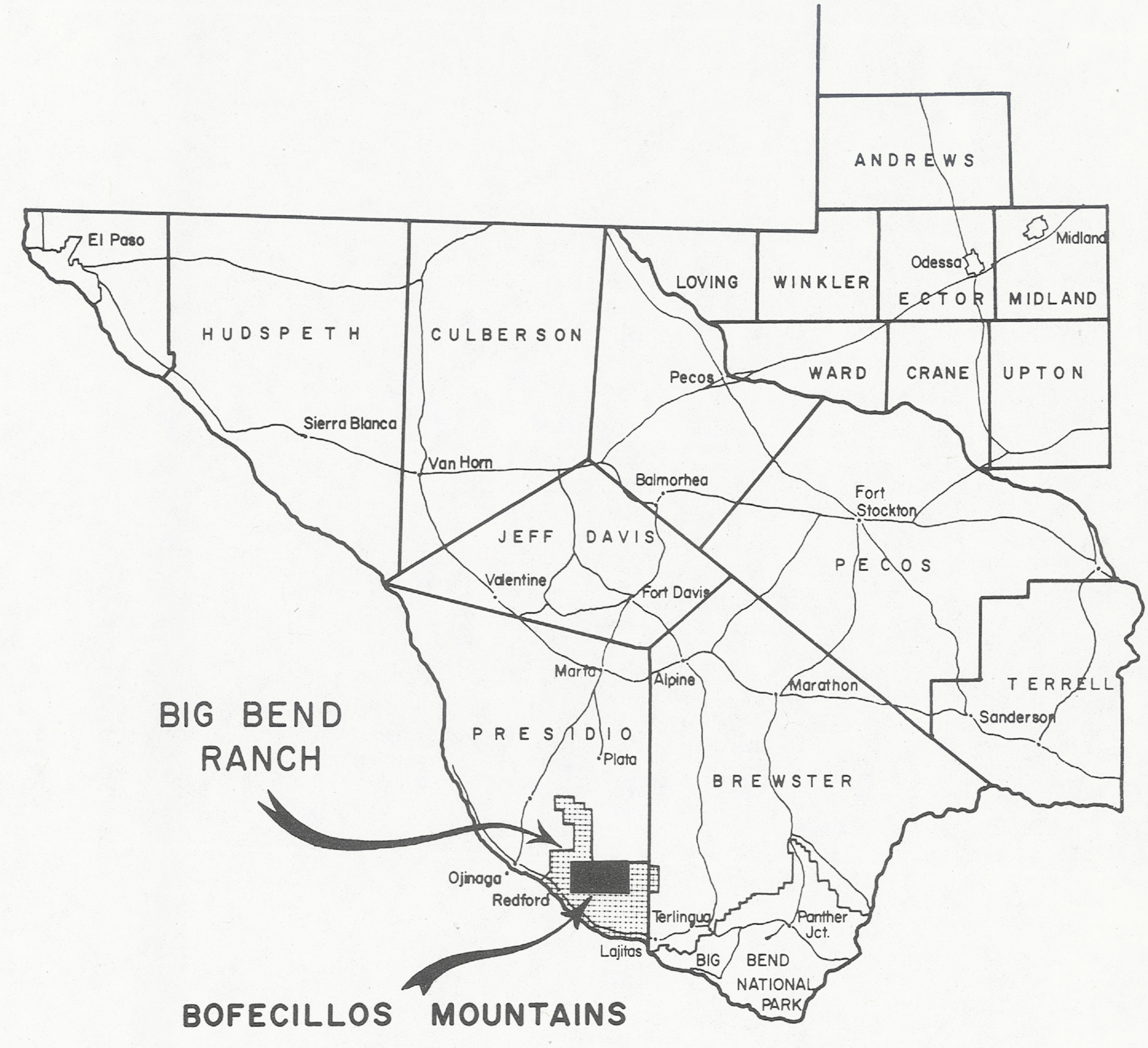

ANDREWS
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BIG BEND RANCH
PRESIDIO
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Redford
Terlingua
Panther Jct.
Lajitas
BIG BEND NATIONAL PARK
BOFECILLOS MOUNTAINS

THE UNIVERSITY OF TEXAS AT AUSTIN
LYNDON B. JOHNSON SCHOOL OF PUBLIC AFFAIRS
AUSTIN, TEXAS 78712

Texas Parks and Wildlife Commission
Pearce Johnson, Chairman
4200 Smith School Road
Austin, Texas 78744

Dear Mr. Chairman:

The Lyndon B. Johnson School of Public Affairs of The University of Texas at Austin respectfully submits herewith its report, The Bofecillos Mountains: A Natural Area Survey, pursuant to the joint request of the Texas Historical Commission, the General Land Office, and the Texas Parks and Wildlife Department, and in fulfillment of Inter-agency Contract (74-75) 1168.

The Bofecillos Mountains, like each of the other areas undertaken at your request, was scientifically and historically surveyed, mapped, and photographed, which involved the recruitment and direction of a field team of geologists, archeologists, botanists, zoologists, paleoentomologists, ornithologists, cartographers, photographers, landmen, and historians.

Texas is a diverse and beautiful land with a rich heritage and abundant natural and scientific wonders that should be preserved for the wise use and enjoyment of ourselves and of generations to come. As your commission pointed out in requesting this survey, the more significant natural areas are disappearing all too rapidly in Texas. It is our hope that the data gathered here will be instrumental in reversing that trend.

Sincerely,

Don Kennard

Don Kennard
Director
Natural Areas Survey

FOREWORD

The Natural Areas Survey project of the Lyndon B. Johnson School of Public Affairs at The University of Texas presents this study of Bofecillos Mountains, a unique Texas natural feature. This report is respectfully submitted to the Governor, the Texas Legislature, and the Texas Parks and Wildlife Commission in order that they be more fully informed about the resources of the state.

All studies in this series were prepared by multidisciplinary teams representing the natural and social sciences. Each study presents a comprehensive survey of the plants, animals, and geology of the area, as well as a review of its importance to man, both ancient and modern. The sites were chosen to fall within the definition of natural areas used in the Texas Outdoor Recreation Plan (Texas Parks and Wildlife Department 1975), "natural areas are areas or sites, which, because of their scenic beauty, rarity, recreation value, uniqueness, ecological importance, or cultural value should be protected for posterity."

There are perhaps a few hundred natural areas remaining in Texas, ranging from sections of mountainous land to half-acre sloughs. They can be found among our mountains, plains, shores, and woodlands. Together they could form a network of wildlife sanctuaries and study areas. It is our hope that citizens and state officials will commit themselves to the cause that these areas be preserved as remnants of the natural world and as sanctuaries for the rare and fragile living things which are succumbing to man's increase on this globe. If these areas are overtaken by development, these studies will provide a bare record of the beauty and scientific wonder which was lost.

With the release of this and the companion reports of this year, the list of project areas now stands at thirteen. Other reports in the series are:

Capote Falls
Matagorda Island
Mount Livermore and Sawtooth Mountain
    (and supplement)
Victorio Canyon
Blue Elbow Swamp
Devils River
Canadian Breaks
Devil's Sinkhole Area—
    Headwaters of the Nueces River
The Solitario
Fresno Canyon
Colorado Canyon
Falcon Dam-Thorn Woodland

ACKNOWLEDGEMENTS

Material for this and the four other reports in this series was assembled and edited by Don Kennard. Editorial contributions to the final manuscripts were made by Griffin Smith, Jr., Senior Editor of *Texas Monthly* magazine, Truett Latimer, Executive Director, Texas Historical Commission, Dr. Marshall Johnston, Professor of Botany, The University of Texas at Austin, Curtis Tunnell, State Archeologist, and Edgar B. Kincaid, Jr.

Color frontispiece was by Reagan Bradshaw. Erlene and Linda Hill were responsible for typography and prepared the layout with the help of B. J. Hill. We are indebted to Dr. Keith Arnold, Dr. Stephen Spurr and Ross Shipman of the Division of Natural Resources and Environment, to the Lyndon B. Johnson School of Public Affairs, The University of Texas at Austin, and to Ronnie Fiesler, Barbara Walker, and John McCully of our staff for their assistance in handling the multitude of details and arrangements necessary to produce these reports.

We are especially indebted to Exxon Co. USA whose interest, encouragement, and generous grant of funds made possible the publication of these reports and significantly enhanced the field research effort of this and other projects undertaken by the Survey.

It is difficult to acknowledge, without omission, the time and effort unselfishly given by so many friends of Texas's natural heritage. With a fear that we may have inadvertently missed others, we wish to give special thanks to:

Robert O. Anderson, Robert B. Anderson, Joe Mims, and Ralph Hager of the Diamond A Cattle Company and the Big Bend Ranch

Bob Armstrong, Commissioner of the General Land Office

Jack Burns, Alpine, Texas

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Texas Historical Commission and its staff

Chairman Pearce Johnson and the members of the Texas Parks and Wildlife Commission

Raul and Enrique Madrid of Redford, Texas

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George Pool, U.S. Public Health Service, El Paso, Texas

Linda Roark, Terlingua, Texas

Anders Saustrup and the staff of the University of Texas Rare Plant Study Center

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IMPRESSIONS OF THE BOFECILLOS MOUNTAINS

Griffin Smith, jr.

Between Redford and Lajitas a line of high bluffs guards the Texas side of the Rio Grande. Rising steeply to promontories nearly 2000 feet above the river's edge, then changing to rolling high country speckled by the dark peaks of 5000-foot mountains, this is the front line of the Bofecillos Range. Twenty million years ago, when the region we now know as the border was a place of glowing cones and vents and smoke and ash and magma, volcanoes built up the Bofecillos; later, as the ancestral Rio Grande broke through the nearby Redford Bolson and began to carve a channel to the Gulf, erosion gnawed away at the adjacent mountains, incising them with tributary canyons.

Today one can drive (albeit with difficulty) to the very lip of one of these high bluffs and look out upon a Texas shaped by earth, wind, and water only; not by man. From the crest of Upper Wylie Mesa one can gaze for 50 miles, past steep striated canyon walls of red and white and brown and yellow, above the talus slopes and trickling water of Tapado Canyon, over the brushy solitude of flat-topped Burro Peak, to the meandering Rio Grande beyond. The only sign of civilization is a speck of irrigated green in the distant Redford valley. From Wylie Mesa it seems less an intrusion than a confirmation of man's insignificance in the scheme of things. One comes to the rim at sunset and finds Texas when it was new.

Until the twentieth century, history circumvented the Bofecillos Mountains. Antonio de Espejo's expedition passed to the northwest, down Alamito Creek, in 1582-83, and Major William Emory followed the Rio Grande southward from Fort Leaton, near Presidio, in 1857. Emory's reconnaissance party included a geologist, C. G. Parry, who provided the first scientific description of the southern Bofecillos; Emory himself recalled that the course of the river, as it narrowed toward Colorado Canyon, was "a section of country which for ruggedness and wilderness of scenery is perhaps unparalleled." But until the Indians' final defeat made ranching possible, few whites had reason to venture past the scenery into those uncharted uplands.

The Bofecillos remain sufficiently unspoiled that a visitor can still find manos which have lain untouched since they were set aside by Indian hands perhaps 400 years ago. Seven canyons—Bofecillos, Auras, Las Burras, Tapado, Rancherias, Panther, and Madera—pierce the mountain flanks from west and south; in them, and in the high country above, the dense aggregation of archaeological sites shows what powerful attractions the Bofecillos held for prehistoric man. Water was evidently foremost: seeps and springs are common, especially in the canyon bottoms. Security was doubtless another: rock shelters were a welcome protection against the elements and possibly against enemies as well. The lithic debris associated with these shelters is often substantial, forming what amounts to cultural talus slopes. Sandals, quids, and animal remains have occasionally been found—a reminder that the clans subsisted by hunting small game and processing tuberous plants. A dense concentration of ovenlike hearths near Rancherias Springs gives a clue to the methods they may have used. Simple patterns of life associated with Archaic times seem to have persisted with little change well into the seventeenth century A.D.

Pictographs are found in Bofecillos, Auras, and Las Burras Canyons—but not, so far as is known, in the four canyons farther east. They reappear in Fresno Canyon, which forms the eastern limit of the Bofecillos Range, but are absent again in the adjoining Solitario. Depicting abstract geometric designs as well as lifelike figures in multicolored pigments, they are a puzzle to archaeologists not only for their geographical distribution but also for their distinctive style; they may, in fact, constitute an isolated form unique to the Bofecillos Mountains.

The reliable water supplies that attracted prehistoric man owe their existence to a fortunate geologic accident. Following deposition of Cretaceous sediment and the coarse-grained Jeff Conglomerate, repeated volcanic eruptions left alternating layers of hard and soft strata in the Bofecillos Mountains. These layers—the Chisos Formation, the Mitchell Mesa Tuff, local ash and lava flows from the Bofecillos Vent, and the Santana Tuff—were penetrated by hot magma, leaving dikes and laccoliths; later they were torn by faults. The simple result of this complex activity was the creation of numerous aquifers in porous zones around the resistant lava flows, aquifers generously charged from rainfall in the high summits of the Bofecillos Mountains. From them, water emerged as seeps and springs throughout the region.

This was the Bofecillos that the Indians knew; it is also the Bofecillos we know today. That fact is more remarkable than it sounds. Throughout West Texas, springs that flowed copiously as short a time as 50 years ago are dead, dried up when the water table was lowered by widespread drilling of wells for ranching and agriculture. Those in the Bofecillos have escaped this fate—not because the overlying land has been used differently (heavy grazing has been practiced there for decades) but because the water for livestock has been obtained differently. Instead of drilling wells at remote locations across the immense Big Bend Ranch, its former owners, Edwin and Manny Fowlkes, erected windmills to pump surface water from the dependable but inaccessible springs to the grasslands on the mesas. After World War II they obtained enormous quantities of surplus pipe and expanded the system across the Bofecillos to Fresno Canyon and the Solitario. At its peak, before they sold the ranch in the 1950s, their implausible, extraordinary pipeline system stretched and twisted across its surface for hundreds of miles, using spring water and the yield from one or two good wells instead of depleting the aquifers artificially. A sizable portion of the system remains operational today. Consequently, the small, isolated Bofecillos watershed functions today as it has for centuries.

The Bofecillos Mountains are more than a geologic laboratory where students can observe in fine detail the internal layering of volcanic action; they are an assemblage of fragile oases. These mountains hold their share of rare and relict plants and animals, but in their entirety they are more: they are, themselves, a relict region.

Like so much of the Big Bend country, theirs is a value beyond measurement. They are the last surviving huge wild part of Texas. In a sense where metaphor comes closer to reality than logic, they are the only "true" Texas that remains. To explore the canyon below Rancherias Springs is to touch for a moment the frontier experience shared, in different landscapes and under different climates, by those who subdued the piney woods, the Hill Country, the Staked Plains, and all the other stern resisting wilderness a century and more ago. The utter solitude, broken by birds and insects only, reconstructs the mood of limitless possibility and vague foreboding that faced everyone who pushed the frontier westward. To experience this lonesome, unbeaten land is to bridge the gulf that separates us from those ancestral settlers, letting us learn physically what we can never fully learn from books and legends.

A BRIEF HISTORICAL SURVEY OF THE BIG BEND AREA

Bruce D. Saunders

Almost hidden in a remote corner of West Texas is a vast area of land that modern civilization has left virtually untouched for decades. The whole region of the Big Bend—bounded on the west and south by the Rio Grande, the Pecos River on the east, and the state of New Mexico on the north—has been a very difficult area to settle. Summer temperatures that can occasionally soar to 55° centigrade (130°F) during the day and then drop rapidly at night, a limited amount of annual rainfall, a scarcity of springs and waterholes, the presence of spectacular but treacherous mountain ranges, all have contributed to the region's lack of early settlers. It is a forbidding area that has attracted only the strongest and most determined individuals who must constantly battle the natural elements found there. Yet there is a beauty and grandeur to the open spaces of this region that the majestic mountain ranges and deep valleys accentuate. Man has been forced to wrestle the land away from the cactus, ocotillo, mountain lions, rattlesnakes, and scorpions that have successfully inhabited the land for centuries. Visitors find the area exhilarating and challenging and often succumb to what columnist and historian Frank Tolbert calls "Big Bend Fever." Walter P. Webb, the noted historian, agreed with Tolbert but pointed out that the malady had an insidious nature because people were often "homesick for a place that could never be their home."[1]

It has always been difficult to exist in this arid land. The early Indian villages were all situated along the banks of the Rio Grande or smaller tributaries to make use of the water and the fertility of the alluvial plains that appeared after the high waters carried soil

Aerial view of Canyon Colorado, better known as the River Road over the Big Hill. This view is to the west, looking up the Rio Grande that can be seen for miles to the left of the also winding road. Until that masterpiece of road construction was completed a couple of years ago, this part of the Big Bend was impassable. Today it is the route of the Camino del Rio. Picture made September 22, 1965.

and deposited it as the floods receded. Life was so precarious that a drought, a crop failure, or another type of natural disaster often destroyed entire villages or forced them to relocate in other areas. Even an environmental shift could upset the delicate balance that allowed the Indians to cling to a subsistence form of agriculture in the river valleys.[2] Archeologists have located early villages along the Rio Conchos, near its confluence with the Rio Grande, and on the right bank of the Rio Grande.[3] The settlement called Tapalolmes, located near the present site of Redford, Texas, was well established in 1747 when Rabago y Teran observed it during his travels. The natives later crossed the river and built a settlement on the left or west bank.[4] Other villages had been observed and described over a hundred years earlier. The intrepid Spanish explorer Cabeza de Vaca crossed the Rio Grande in 1535, but the exact location of his route has been a subject for lively debate among historians, geographers, and geologists. There is little doubt that he visited the La Junta de los Rios (the confluence of the Rio Conchos and the Rio Grande) area, named the local Indians "the people of the cows," erected a cross, and designated the area "La Junta Pueblo de las Cruces."[5] Robert T. Hill, the famous American geologist of the Trans-Pecos region, maintained that de Vaca wandered from a location near the present site of Ft. Davis on a southwestern course that carried him down Terlingua Creek to Lajitas and then across the Rio Grande at or near the famous San Carlos ford. He then continued on a southwestern heading but reversed his course and took a northern route to La Junta.[6] Hill based his findings on de Vaca's accurate descriptions of the geographic and geologic features he passed in west Texas. Hill was unable to understand why a large number of historians had been unable to correctly plot de Vaca's route.[7]

Many of the early settlers of the Big Bend area and the people that lived along both sides of the Rio Grande who were present when de Vaca came through west Texas were cave dwellers. They spent part of their time in dry caves above the river and the rest of it along the rivers and arroyos planting and harvesting crops.[8] A larger and more organized tribe, the Jumanos, were active in the La Junta area from 1650 until the 1770s. They were first critically observed when the Antonio de Espejo expedition passed through the La Junta area in 1582-1583. They were good farmers but never practiced irrigation, a fact that brought starvation as a constant visitor to the tribe. The Jumanos possibly were related to the pueblo-building tribes who spread southward along the Rio Grande. They allied themselves with the Apaches, their former enemies, during the 1693-1715 period, yet there was still a gradual reduction in the size of their tribe during the 18th century.[9] There is very little accurate information available on this tribe, and, as Newcomb states, "of all the Texas Indians, the Jumanos are the least known, and the few facts about their culture we do possess seem to raise more questions than they answer."[10] He concludes that they were "an important outpost of civilization, a pioneer people who had been temporarily successful in establishing settlements on the fringe of Puebloland."[11]

The Jumanos and the other tribes of the southwest were often viewed as subjects for conversion to Catholicism. A number of *entradas* and *visitas* crossed into the Trans-Pecos area, commencing in 1581 when the Fray Augustin Rodriquez expedition reached La Junta on July 6.[12] Composed of three priests, a sergeant, 19 Indian scouts, and 600 head of cattle, sheep, goats, and hogs, its major purpose was to explore the territory and christianize the natives.[13] The Espejo *entrada* left San Bartolome in early November, 1582, with a complement of 15 soldiers, some servants, a priest, and over 100 horses and mules, to rescue the members of the Rodriquez expedition. Espejo, a wealthy Mexican citizen who was attempting to atone for a crime he had committed, financed and led the expedition as it marched up the Conchos River to the Rio Grande. On December 9, 1582, it arrived at La Junta, where the horses were rested for eight days before it headed northward to El Paso del Norte.[14] Espejo eventually led his men farther north to Santa Fe, then east to the Pecos River, down it to the Sheffield Crossing, west to Kokernut Springs (Alpine), and then down Alamito Creek to the Rio Grande, just south of Presidio, Texas.[15] The Dominquez de Mendoza expedition explored the area north and east of La Junta and travelled up Alamito Creek to Alpine.[16] Both the Espejo and Mendoza expeditions opened a new trade route from Mexico to the United States that remained virtually unused for a century and a half.

An American expatriate was the first man to realize the value of the route that the early explorers had found. Dr. Henry Connelly was a Kentucky physician who moved to Chihuahua, Mexico in 1828. He worked as a clerk in a retail store for a Mr. Powell, saved his money, and later bought the business from Powell. Dr. Connelly left Mexico in April, 1839 via the Rio Conchos to La Junta, crossed the Rio Grande, and headed up Alamito Creek. Eventually he reached his destination, Independence, Missouri. There he loaded either pack mules or a wagon train with goods to sell in Mexico. His first round trip lasted 16 months and was very successful. With Edward J. Glasgow, another American expatriate in Chihuahua, he formed a partnership that continued in

The Crawford Ranch and small farm in Fresno Canyon, lower part of Brewster County, about 1918. It was in an isolated location, but several Army mule pack trains passed by every week, going to and from Lajitas when a cavalry troop was on the Rio Grande. Through the Fresno Canyon was the main route between Lajitas, Terlingua and Marfa then, but not after 1920. Mr. Crawford had the largest goat herd in this part of the Big Bend, and he also grew the first citrus fruit in this part of Texas (oranges and lemons).

a profitable manner until the end of the Mexican War in 1848. Connelly married a Mexican woman and fathered three sons before he moved to the United States States just after the Treaty of Guadalupe-Hidalgo was signed. In 1849 he settled in the New Mexico Territory where he purchased the largest mercantile store in the region. In 1861 and again in 1864, President Abraham Lincoln appointed him territorial Governor, a post he held until the time of his death in 1866.[17]

Connelly's Trail, better known as the Chihuahua Trail, opened a prosperous era for the Missouri merchants and for the Rio Grande Valley area near La Junta and Presidio. After the Rio Grande was finally and firmly established by the Treaty of Guadalupe-Hidalgo as the boundary between the United States and Mexico, new residents began slowly to settle along the river in order to profit from the growing commerce between the United States and Mexico. One of the earliest settlers was Ben Leaton who relocated near the San Jose Mission in 1848 on some land that his wife, the former Doña Pedraza, had purchased in 1833. Leaton, who was born in Kentucky and later lived in Chihuahua, opened a very lucrative trading post, El Fortin. Later called Fort Leaton, it attracted business from the Indians, American travellers and merchants, and Mexicans who crossed the river to trade. Leaton, a mysterious man, disappeared in the early 1850s, setting off a long and complicated series of court battles over his land.[18] Fort Leaton is in the process of being reconstructed on its original location several miles south of Presidio near the mouth of Alamito Creek.[19]

Fort Leaton, the outpost of civilization in the Big Bend region, was a favorite stopping point for Americans who crossed the Chihuahua Trail or who were exploring the area. One of the first groups of visitors included Colonel Jack Hays. He had been commissioned, along with Samuel Highsmith, to find a new trade route between San Antonio and El Paso del Norte. Businessmen in San Antonio had raised over $800 to finance the expedition of 35 Texas Rangers and Indian guides. They left the Alamo City in August of 1848, undoubtedly never believing that they would almost starve to death before reaching the security of Fort Leaton in late October.[20] Samuel Maverick, a veteran of the Mier Expedition and the

Mexican War, kept a detailed diary that indicates the problems they encountered. It took a month to reach the Devil's River. After crossing it, they entered the Big Bend region and became lost. Maverick's diary illustrates their suffering. September 29: men were "crawling like flies on side of mountain." October 2: "To banks of the Rio Grande, where we killed and ate a panther." October 4: "Mustang meat in request." October 7: "No food. Here we begin to eat bear grass." October 10: "Killed a mule. Meat poor and tough." On October 19, the weary band reached the small Mexican town of San Carlos, mainly through some directions a group of Indians had given them, and obtained bread and milk to restore themselves.[21] They travelled north from San Carlos, crossed the Rio Grande, and spent 16 days at Fort Leaton recovering from their ordeal and resupplying for their return trip to San Antonio. Hays ruled out any thought of a continuation of the trip to either El Paso de Norte or Chihuahua City.[22] Although the Hays-Highsmith group was the first expedition to reach Fort Leaton from San Antonio, the results of the trip were not impressive or satisfactory. One member of the party, Dr. Wahm, went insane and deserted as the expedition wandered aimlessly in the Big Bend region. The Indians found and cared for him and later permitted him to return to San Antonio a year and a half after he first left with Hays and Highsmith.[23]

The year after the Hays trip, the United States Army, eager to find a shorter route to the west, dispatched Lieutenant W. H. C. Whiting of the Corps of Engineers to seek a safe route from San Antonio to El Paso del Norte. He had difficulty traversing the Trans-Pecos area but reached Fort Leaton in six weeks. He resupplied there and enjoyed the type of hospitality that made Ben Leaton famous throughout the west. Whiting recorded in his diary that he dined on stewed chicken with chili, tortillas, roast turkey, frijoles, coffee, and whiskey, with Leaton's famous peach brandy as an after-dinner drink.[24] Whiting and his assistant, Lieutenant W. F. Smith, continued up the Rio Grande to El Paso del Norte and returned to San Antonio via a new route that ran southwest between the Pecos and San Pedro Rivers to Las Moras Creek and then into San Antonio. It was an improved route that covered an estimated 645 miles.[25]

Following Whiting's successful mission, the Army attempted to find a shorter and safer route to El Paso del Norte via the Rio Grande. Captain John Love proceeded from Ringgold Barracks, near Rio Grande City in the lower valley, up the river to a spot he estimated as 1,014 miles from his starting point. He led a company of a dozen men, using a flat-bottomed boat that measured 50 by 16 feet and drew only 18 inches of water. They used this boat for what he estimated to be the first 967 miles, but at Brooks Falls they changed to a smaller boat that took them to an impassable point they believed was 25 miles south of Presidio. While they failed to navigate all the way to El Paso del Norte, they considered they had proved that over a thousand miles of the Rio Grande was navigable, even if only in small boats.[26] Love's report was quickly contradicted in another Army document that stated that the Rio Grande was only ten inches deep above Eagle Pass and thus impassable much of the year. The second report, the work of a small party of Army men under the command of Lieutenant Martin Luther Smith, was based on a trip via flat boats to a point eight miles above the confluence of the Rio Grande and the Pecos Rivers.[27] Despite Capt. Love's optimistic report, the Rio Grande was not the best route from San Antonio to the Big Bend Region, El Paso del Norte, or Chihuahua City.

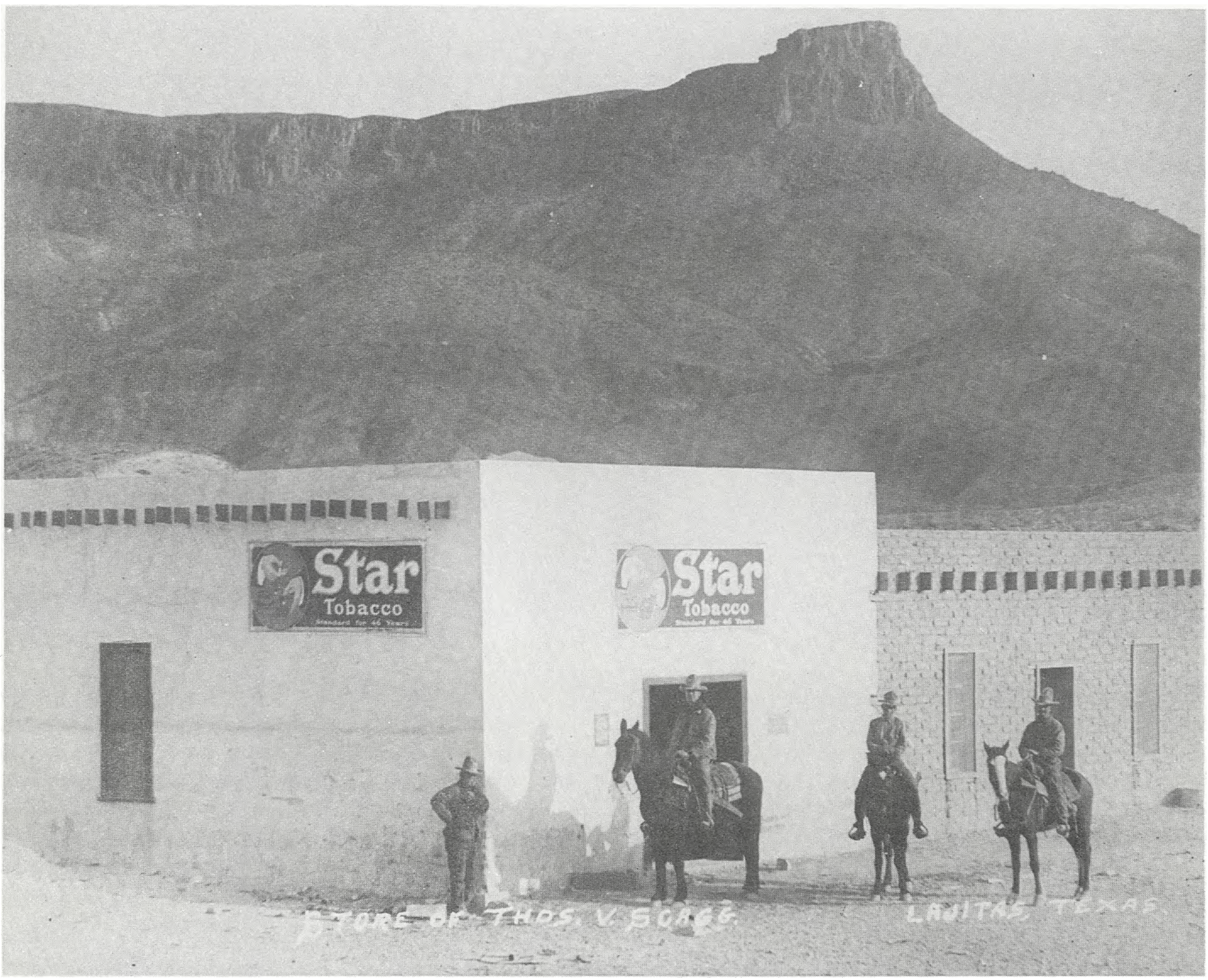
American interest in the exploration of the southwest continued for other reasons. Pursuant to the terms of the Treaty of Guadalupe-Hidalgo, the United States Army organized a number of reconnaissance missions that were ordered to survey carefully the border region along the Rio Grande. John Russell Bartlett was the first Boundary Commissioner, but his poor knowledge of the west, problems with the Indians, disagreements with Mexico, and a shortage of funds sharply curtailed his effectiveness.[28] Major William H. Emory, an astronomer attached to the Topographical Corps of the United States Army, assumed command of the surveying party as it started to work its way south along the Rio Grande to its mouth. Emory faced numerous problems that included the severity of the climate, lack of funds to pay his men or purchase supplies, and the rugged nature of the terrain he had to map. Emory and his skilled assistants carefully classified and catalogued the flora and fauna they found along the length of their route. They were most impressed when they travelled from Fort Leaton south toward the canyons of the Rio Grande. Emory remarked that it was "a section of country which for ruggedness and wilderness of scenery is perhaps unparalleled."[29] They observed that a one-to-three-mile-wide valley extended from Fort Leaton south to the Bofecillos Mountains where it narrowed to form a canyon. Farther to the south, near the present Lajitas Trading Post, Emory reported that the Comanche Pass ford was the "most celebrated and frequently used crossing place of the Indians."[30] He happened to meet Chief Mano of the Apache Tribe who was leading a band of men through the ford to Durango, Mexico.[31] Emory's work in the Big Bend region was the first detailed scientific exploration completed in the Big Bend region, but other men who followed added more information to his collection of samples and observations.

All of these explorations of the area and the continued expansion of American interests convinced several Americans living in Mexico that the border region along the Rio Grande near Presidio and immediately to the south held the promise of commercial success. Milton Faver, like Ben Leaton, came to Presidio after living in Mexico and marrying a Mexican woman. He ran a freight line between Ojinaga (near La Junta) and Meoque and later operated a general store in Ojinaga, but he finally moved to the west bank of the Rio Grande and eventually owned four large ranches to the north and east of Presidio. He was one of the most successful ranchers in the region and amassed a herd of over 20,000 longhorns before his death in 1889.[32] John W. Davis settled near Alamito Creek where he raised horses and cattle in the 1850s. He employed between 15 and 20 Mexican families to operate his ranch. He decided to leave the southwest in 1892 to return to his native North Carolina after the death of his Mexican wife.[33] John W. Spencer, one of Leaton's original business partners, moved with his Mexican wife and large family to the American side of the river in the 1850s to enter the horse-raising business near Fort Davis. The Indians stole most of his stock, so he moved back near the Rio Grande for security reasons, settling north of Presidio and entering the cattle business.[34] John D. Burgess, another early businessman in the Presidio area, followed the same general pattern as Leaton and Spencer. He entered the freighting business in 1851 and then bought some land on the American side of the river and went into competition with Leaton. He took over Leaton's Trading Post and continued to work in the freighting business for the next 20 years. He became entangled in a bitter feud with several of Leaton's heirs, including the new husband of Leaton's widow.[35]

Both Burgess and Leaton recognized the need for adequate transportation in the Big Bend area. The freighting business was a lucrative occupation for many individuals who ran lines both in Mexico and the United States and profited from the growing trade between the two nations. Connelly's Chihuahua Trail was the first successful route connecting northern Mexico with the American midwest, but other routes were needed. In 1869 August Santleben inaugurated a stagecoach route between San Antonio and Chihuahua City via Fort Stockton and Presidio. He made a number of round trips in the 1870s, carrying goods of all types, especially silver from the Mexican mines. In 1876 he attempted to organize a large-scale freighting business in Chihuahua City, but the completion of the El Paso del Norte-Chihuahua City railroad forced him to abandon his plans.[36] Henry Skillman's San Antonio-El Paso mail route, established in 1850, was extended to Presidio on the Rio Grande on a weekly basis in 1870 and brought the area into closer contact with the rest of Texas and the United States.[37] Drivers on the Chihuahua Trail used the prairie schooner as their principal vehicle. It had a bed 24 feet long but was only 4½ feet wide with wooden sides that extended to a height of 5½ feet. The rear wheels were almost six feet high, while the front wheels were a foot shorter. A team of 16 mules pulled an average load of 14,000 pounds. Drivers had to have the skills of a mechanic, a veterinarian, a gunfighter, an overland navigator, a cook, and a businessman to survive on the trail.[38] The advance of the railroad hastened the end of mule-drawn freight wagons and the lines that served many remote areas in the southwest. The Rio Grande area was bypassed in 1883 when the Southern Pacific Railroad crossed the Trans-Pecos region to the northwest of the river, helping to found and promote the towns of Sanderson, Marathon, Marfa, and Valentine along its route. A line did not reach to the Rio Grande until 1930 when the Atchinson, Topeka and Santa Fe linked Alpine and Presidio and provided a connection, via the Mexican National Railroad, to the west coast of Mexico.[39]

Adequate transportation and the location of United States Army posts in the southwest were closely connected to the success of the cattle business in the Big Bend area. Railroads were used to bring in many of the initial herds and to transport the steers to the markets in the midwest. The location of a major Army garrison at Fort Davis in 1854 had an important impact on the establishment of the cattle business in the Big Bend since the demand that Fort Davis generated for fresh beef helped to accelerate the growth of many ranches.[40] Frequent Indian raids, a hot and arid climate, and the long distances to markets continued to frustrate many ranchers. The rich grasses of the region, especially the numerous varieties of grama grasses, that existed in "the most profuse abundance over the entire surface of these table lands, is nutritious during the whole year, and the plains between the Rio Grande and the Pecos seem intended by nature for the maintenance of countless herds of cattle."[41] The early cattle were Mexican and Spanish breeds, but these were gradually replaced as the Texas longhorns were brought into the area. The longhorns, which were seen in many colors, interbred with the native stock to produce a large wild animal that could survive on the native grasses without requiring large amounts of water.[42] Early cattle drives were organized in the 1860s, headed not toward the markets in the midwest but along the Chihuahua Trail into Mexico. These drives, which reached their peak in 1868-1869, were safe from Indian attacks but often fell prey to the raids of the Mexican rustlers that attacked along the route.[43] The most prosperous period for the cattle industry in the Big Bend region came in the 1880s. A land rush during the first part of the decade resulted in the formation of many large ranches. J. T. Gano founded the Estado Land and Cattle Company in 1885 on 55,000 acres with 6,000 head of cattle he brought in from Dallas and Uvalde.[44] Meyer Halff started his ranch with 50,000 acres and added more later while Milton Faver in the 1880s controlled four large ranches with between 10,000 and 20,000 head of cattle.[45] The severe winter of 1885-1886 helped to push over 60,000 head of cattle into the Big Bend, but it proved disastrous as they quickly overgrazed much of the open range. The first large-scale cattle roundup was held the following summer, August, 1888, to sort out the strays and to help preserve the rapidly diminishing grasslands.[46] The introduction of barbed wire in 1888 and the appearance of the Hereford about the same time ended the first significant era in the cattle business.[47]

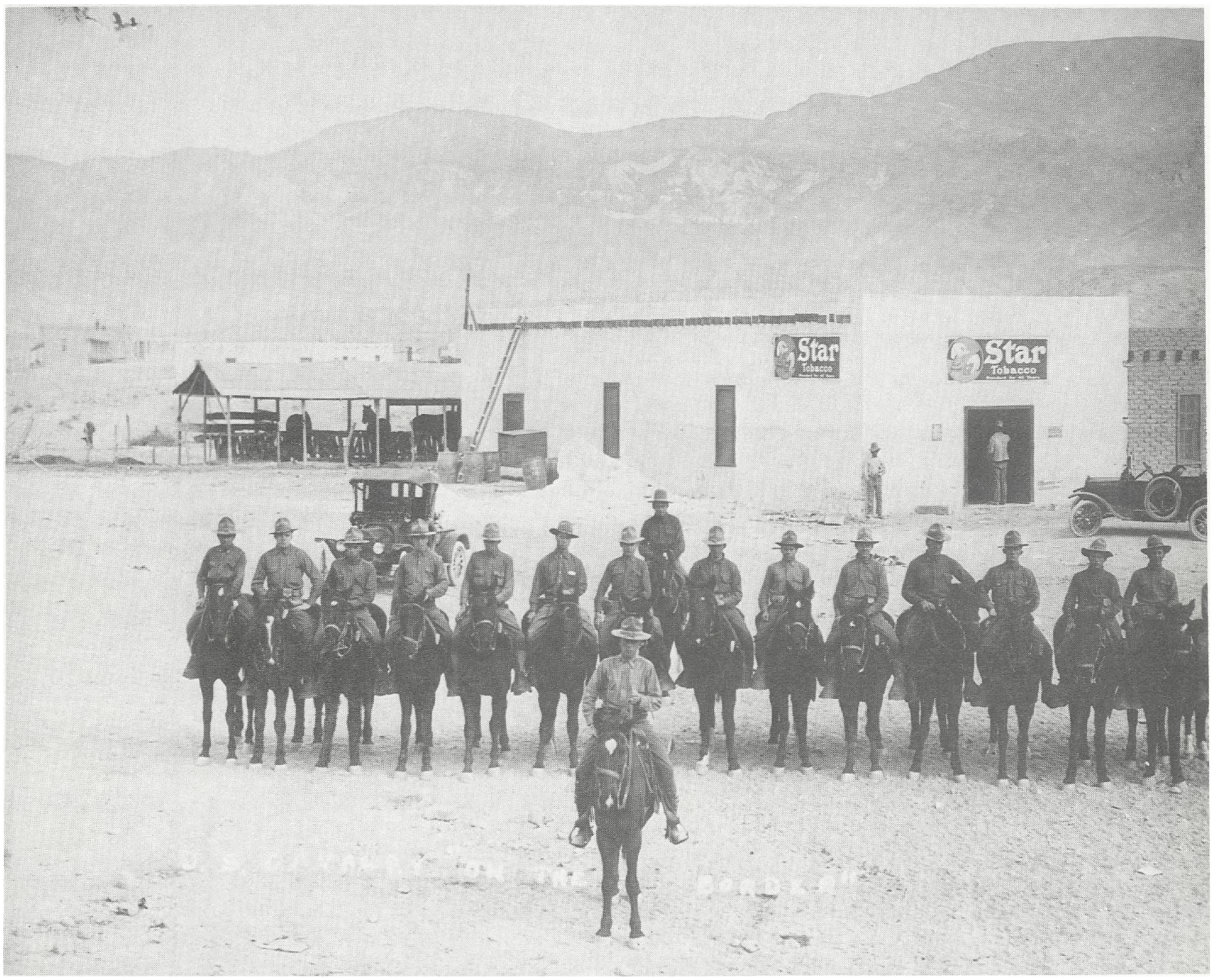
Less romantic, but still economically significant to



The trading post farthest from a railroad on the Mexican border was at Lajitas, Texas. It was 108 miles from Alpine or Marfa, Texas. From 1911 through 1920, it probably was also the busiest for in *that* period its regular large Mexican border trade area on both sides of the Rio Grande was made larger by the numerous quicksilver mines nearby. The largest mine at Terlinqua had its own store but the small mines did not. This picture of Thomas V. Scaggs' Trading Post at Lajitas, Texas, was made in 1916. It shows Scaggs at the corner of his store building talking to Texas Ranger Jeff Vaughn, Cavalry Officer Lt. Stilmax, and Texas Ranger Bill Palmer. A troop of the 6th Cavalry and these two Texas Rangers were stationed at Lajitas.

the area, was the sheep industry that Milton Faver founded. He was the first important sheepman to battle the cattlemen for a place on the open range for his flocks in the 1880s.[48] Although the first sheep were introduced in the La Junta region in the 1560s, they did not play a major role in the economy until three centuries later when their total economic value exceeded the value of all the cattle in Texas.[49] Ranchers like Faver fought for the sheepmen, introduced improved breeds, and persuaded others like George Crosson to enter the business. Crosson bought 1,800 ewes from Faver's large flock in the 1880s and was able to enlarge his own holdings to over 20,000 head by 1889.[50] The 1892-1893 drought crippled the sheep business in the Big Bend, and the Cleveland administration's interference with the Wilson-Gorman Tariff of 1894 caused a large reduction of the duty on raw wool that dealt another serious blow to the sheep raisers of the United States, especially in Texas. The sheepmen of the Big Bend did not recover from these disasters until the 1930s.[51]

Although the region along the Rio Grande was somewhat better suited for livestock, a number of successful farms were started in the 1870s. Using water from the river to supplement the limited rainfall on the rich alluvial soils, farmers were able to "raise any crop that grows in Texas," according to an early report from a civil engineer. "Its (the area between Presidio and Redford) yield is enormous, as much as 80 bushels of corn and 50 bushels of wheat being grown to the acre."[52] Irrigation of these fertile lands began in the 1870s just south of Presidio and



This picture was made in 1916 at Lajitas Texas, of Thomas Scaggs Trading Post and part of a troop of the 6th Cavalry. It is not known which troop these troopers belonged to as the troops were rotated. The officer was Lt. Stilmax. The cavalry had its stables at the rear of the trading post when this picture was made but later moved them beyond the second large white building.

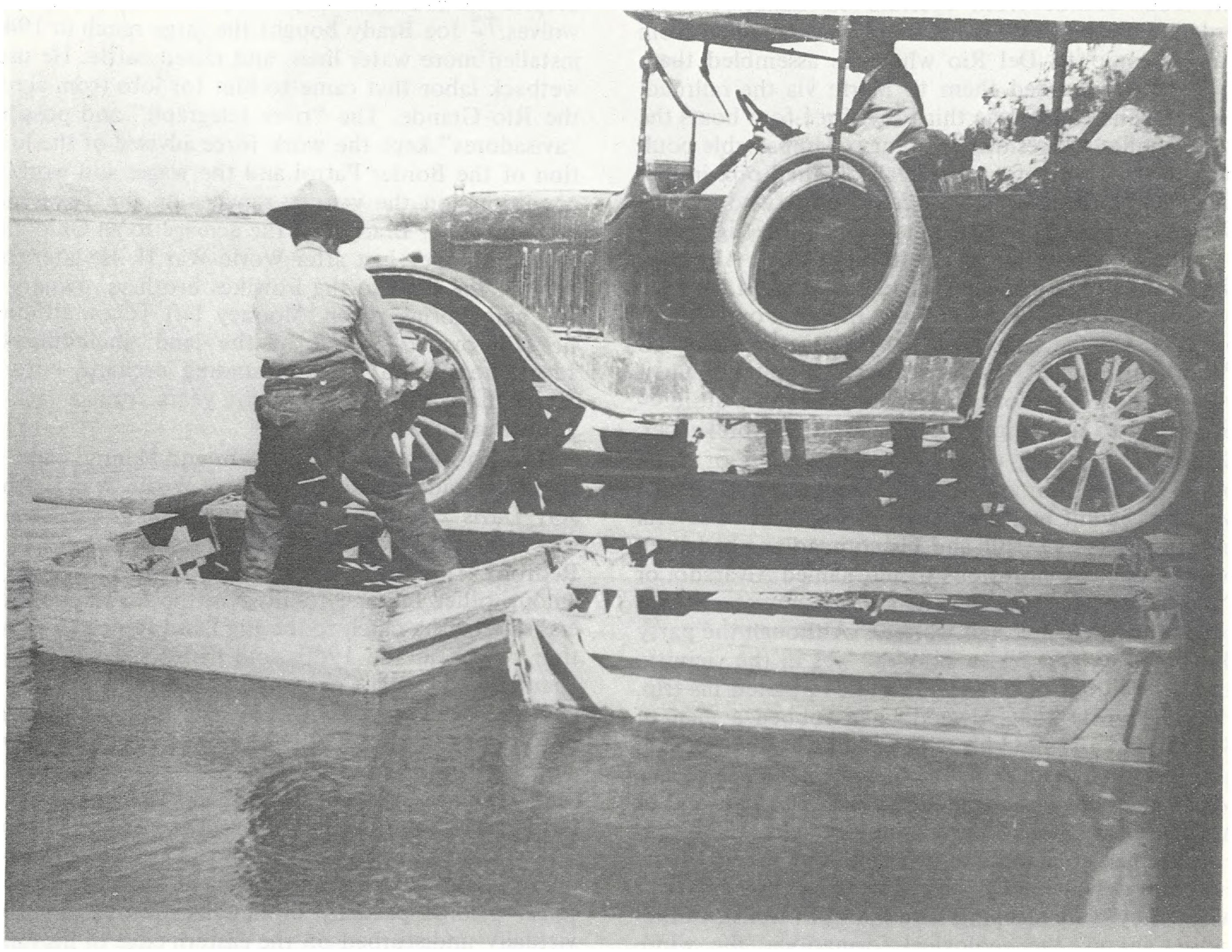
Two wagons pulled by burros and loaded with handmade ropes were being hauled from Lajitas 108 miles to Alpine, Texas, in 1921. They were made by Mexicans in Mexico, sold to Scaggs' Trading Post in Lajitas, Texas, as there was no market for them in this part of Mexico, where everybody made their own ropes.

extended to Redford. One of the earliest farmers in the area was Secundio Lujan who obtained a quarter section of land (160 acres) from the state of Texas in 1875. To obtain water from the river to irrigate his land along its course, he formed the Polvo Irrigation Company. It constructed a 550-foot dam of loose rock, from two to four feet high, that channeled water into an irrigation canal five miles long, six feet deep, and six feet wide at the top. To blast through the hard, igneous rock that he found along the route of the canal, Lujan had to travel over 200 miles to Chihuahua City to purchase gunpowder. He was a very successful farmer, growing beans, onions, corn, and wheat, and later concentrating on cotton.[53] Cotton production totalled 97 bales in 1921 but increased dramatically to 4,789 bales in 1930.[54] Recently farmers have concentrated on onions and the famous Presidio cantaloupes.[55] Other crops just north of the Polvo/Redford area included beans raised after crops of oats, barley, and wheat had been harvested. A few crops, such as corn and beans, were occasionally grown without the benefit of irrigation, usually just north of Presidio where the water level of the Rio Grande was unpredictable and often too low to permit construction of irrigation projects.[56]

As the twentieth century neared, the arid region along the Rio Grande was relatively prosperous but still thinly settled. Presidio County had only 580 residents in 1860 and 40 years later could boast of an increase to 4,125, a substantial gain but very few residents considering the size of the county.[57] Transportation was still slow and difficult, but improving. Ranching and farming occupied most residents. Silver mining developed into a major industry at Shafter, about 30 miles from the river, where the metal was first discovered in 1882 and mined continuously for 40 years. An estimated two million tons of ore produced about $20 million in silver during the operating days of the mines.[58] Farther south, cinnebar, the ore for mercury (commonly called quicksilver) was mined from 1892 until 1971.[59] About one-fourth of all the mercury produced in the United States came from these mines.

One other important natural resource of the area is the native candelilla wax plant (*Euphorbia antisyphilitica*). It grows in abundance on the colluvial limestone slopes and gravel terraces on both sides of the Rio Grande. The plant is harvested and boiled in an acid bath to produce a high-quality wax which is used in chewing gums, floor and auto polishes, crayons, cosmetics, lubricants and a variety of other products. Wax produced in Mexico is supposed to be marketed through the Bank of Mexico, although much of it finds its way across the border and is marketed with the relatively small quantity of wax produced in Texas.[60]

The growing prosperity of the area along the Rio Grande was threatened in the first two decades of the twentieth century when the political and social unrest that spread across Mexico spilled into the United States. In the early part of the century, the Big Bend area had been relatively peaceful since the last raids of the Indians had been effectively ended in the 1880s when a large force of American soldiers had been stationed in a series of forts along and near the border. Francisco (Pancho) Villa, the Mexican bandit and outlaw, often crossed the border into Texas when the Mexican authorities were chasing him. He occasionally hid with his men in the Alamito Creek area, safe from capture but a threat to the stability and peaceful nature of the area.[61] The United States Army was ordered into the area in 1916. A small detachment of cavalry was stationed at the Lajitas Trading Post, and others were garrisoned at Marfa. Aircraft permitted the early pilots of the U.S. Army Signal Corps to patrol the river and locate potential problems before they grew too large to handle.[62] Border raids were common throughout this period.



In 1921 when this picture was made, and earlier, the Rio Grande always had more water than it has today. Then there were not as many large irrigated farms along it. At Lajitas, where this picture was made, occasionally an auto had to cross the Rio Grande, as this Model T Ford of a Texas mining man who had been to San Carlos or some other mining town in the state of Chihuahua. There was a Mexican at Lajitas who had a couple of wooden flat bottom boats that could be converted into ferry boats big enough to cross an auto, as this picture shows.

An estimated 80 Mexican bandits crossed the border during the night of May 5, 1916, to raid both Glenn Springs and Boquillas, Texas. A number of residents were killed, including several American soldiers. President Wilson retaliated by sending a large force to patrol the border region. Another serious raid occurred more than a year later at the Brite Ranch, located near Valentine.[63]

While ranching and farming continued and the border bandits crossed the river to rustle cattle and rob storekeepers, another new industry for the Trans-Pecos area was being established. Robert T. Hill, a geologist, was perhaps the first person who recognized the natural beauty of the Trans-Pecos region, especially the area along the Rio Grande. He planned and led the first successful expedition that explored the Rio Grande from Presidio to Langtry.[64] He ordered the lumber for his three boats shipped from San Antonio to Del Rio where he assembled them and then forwarded them to Marfa via the railroad. Hay wagons carried the thirty-by-three-foot boats the last 75 miles to Presidio. Warnings of impassable boulders in the river, of an outbreak of small pox in Presidio del Norte, and of Mexican bandits who roamed the area frightened off two members of the eight-man expedition before it even got to the river.[65] Although the International Boundary Commission said the river was impassable, Hill set out with five men on October 5, 1899. On the second day of the trip they reached Polvo (in Spanish "dust"), "an appropriately named village" of a half-dozen adobe houses and a store.[66] Stopping to investigate, Hill met the storekeeper, Samuel J. Hensley, who pointed out spots of dried blood on the floor and walls that had resulted when a Mexican bandit had murdered his predecessor several months earlier.[67] Hill and his companions had been warned about a notorious bandit named Alvarado, or "Old White Lip" because half of his moustache was black and the other half white.[68] Although the party did not see "Old White Lip," he was in the vicinity, and several months after Hill had completed his trip, Hensley wrote that Alvarado had robbed a man of $1,200 and assaulted his wife near the area where Hill and his men had camped. Shortly afterwards, the Mexican police shot and killed Alvarado and one of his lieutenants.[69] To prevent any attacks, Hill ordered one man to stand guard over the members of the expedition while they were portaging their boats or when they were sleeping. The 600-foot walls of Colorado Canyon, the geological formations, the wind-eroded rocks, and the size of Santa Elena Canyon all impressed Hill.[70] His descriptive coverage of the river trip that appeared in *Century Magazine,* along with his other field work in the Trans-Pecos area, helped to stimulate interest in the region along the Rio Grande.

Although tourism was increasing and the scientific community had begun to take an active interest in the natural features of the area, ranching continued as the most important economic activity. Older ranches, like the C. H. Madrid spread founded in the 1870s, survived the severe drought of 1892-1893 and were prospering in the 1920s. The Madrids built a water system from a spring to the ranch house and maintained a small orchard of peach, orange, and fig trees, using the irrigation system they had constructed.[71] The D. H. S. Smith ranch, a short distance north of the Madrid Ranch and in Fresno Canyon, grew out of a land grant to the Dallas and Wichita Railroad in 1881. J. L. Crawford later assumed control over it, but sold it to Harry Smith in the 1930s. Smith grazed from 3,000 to 4,000 Angora goats on the ranch, despite the attacks of coyotes, panthers, bobcats, and wolves.[72] Joe Brady bought the large ranch in 1941, installed more water lines, and raised cattle. He used wetback labor that came to him for jobs from across the Rio Grande. The "river telegraph" and possibly "avisadores" kept the work force advised of the location of the Border Patrol and the wages and working conditions on the various ranches on the Texas side of the river.[73] Brady sold the acreage to an Ohio man named Mooney just after World War II. He later sold part of the land to the Fowlkes brothers, owners of the neighboring ranch. Mooney left Texas, although he still owned a part of the land, including the ranch house and the surrounding orchard, both of which have suffered in recent years from a lack of maintenance.[74]

The Fowlkes brothers, Edwin and Manny, came to the Big Bend area shortly before World War II from Jeff Davis County to the north and gradually put together a large (almost 200,000-acre) ranch north of Redford. The severe seven-year drought of the 1950s, among other factors, resulted in the Fowlkes brothers' sale of the ranch to the Big Bend Ranch Corporation, which in the 1960s sold to Robert Anderson's Diamond A Cattle Company. Anderson continues to operate the large ranch, which, by lease or purchase now contains about 320,000 acres, straddling two counties, Presidio to the west and Brewster to the east. He grazes cattle in the Fall and Spring and opens it to hunters during the deer season. An ardent conservationist and naturalist, Anderson has permitted many scientific groups to visit and explore the Solitario, a large partially eroded laccolith that stands virtually undisturbed on the eastern edge of his ranch property. Its outstanding geological formations, archeological sites, flora, and fauna form a large open research site for many scientists.

Life along the river continues at the same leisurely pace that de Vaca must have observed over 400 years ago. But new interest in the scientific treasures of the area, in the beauty of the mountains and the arroyos, and in the desire to enjoy the vast openness of an undisturbed region has brought more people than ever to this remote sector of Texas. Following the modern highway south from Presidio, a visitor can see the green farmland on the alluvial plains of the Rio Grande, pass through the small town of Redford, and approach the first of the numerous breathtaking canyons of the Rio Grande. Driving along the river in air conditioned comfort, it is hard to imagine that de Vaca walked through this area, or that Echols drove camels on this route from Presidio in 1860, or that Colonel Jack C. Hays and his men wandered for 12 days without food just to the south of this spot. Just below Black Rock Canyon, the small village of Lajitas, population nine, slumbers in the warm sun. Again, it is hard to picture elements of the United States Cavalry garrisoned at the Trading Post or the international transactions for cattle being conducted on a sandbar in the middle of the river. It is even more difficult to visualize the Comanche bands as they once swooped down their trail to cross the San Carlos Ford to invade Mexico to loot and kidnap the natives. The full September moon was known as the "Mexican Moon" in Comanche camps as it signaled the time for another raid, but in northern Mexico the same moon was called the "Comanche Moon," and people fled to the mountains to protect themselves and their property.

Farther to the south of Lajitas lies the awesome Santa Elena Canyon that lured Robert T. Hill in 1899 and today attracts thousands of outdoorsmen and adventurers who paddle their canoes and rubber rafts down the river between the canyon's steep walls. It is now part of a 700,000-acre national park that was formed after the land was given to the National Parks Service. Big Bend National Park protects the natural beauty of the area and guards the flora and fauna of this unusual region from destruction. The area just above the park, rich in natural beauty and with a wealth of scientific treasures, would be enhanced by the same type of protection to preserve its rich historical background.

Pictures and captions of photographs in this section are from The Smithers Collection, Photography Collection, Humanities Research Center, The University of Texas at Austin.

NOTES

1. William O. Douglas, *Farewell to Texas: A Vanishing Wilderness* (New York, 1967), 48. This current brief survey was written without the benefit of Ronnie C. Tyler's *The Big Bend: A History of the Last Texas Frontier* (Washington, 1975), a very thoughtful and detailed treatment of the area, which appeared in print after the survey had been completed.

2. J. Charles Kelly, "Factors Involved in the Abandonment of Certain Peripheral Southwestern Settlements," *American Anthropologist,* 54 (July-September, 1952), 382-385.

3. See J. Charles Kelly, "The Historical Indian Pueblos of La Junta de los Rios," *New Mexico Historical Review,* 24 (October, 1952), 251-295 and 28 (January, 1953), 21-51 and also Howard G. Applegate and C. Wayne Hanselka, *La Junta de los Rios Del Norte y Conchos* (El Paso, 1974) 2-23.

4. Kelly, "Historical Indian Pueblos," 28 (January, 1953), 40-41.

5. Cabeza de Vaca, "The Narrative of Cabeza de Vaca," trans. by Frederick W. Hodge, in Hodge, ed., *Spanish Explorers of the Southern United States,* 1528-1543 (New York, 1907), 99-105.

6. Robert T. Hill, "Cabeza de Vaca Crosses the Rio Grande at Last," *Dallas Morning News,* March 11, 1934, 8.

7. *Ibid.*

8. Victor J. Smith, "Survey of Indian Life in Texas," West Texas Historical and Scientific Society *Circular,* No. 5 (1941), 8-10.

9. W. Newcomb, *The Indians of Texas: From Prehistoric to Modern Times* (Austin, 1961), 228-234 and Herbert H. Bolton, "The Jumano Indians in Texas, 1650-1771," *Southwestern Historical Quarterly,* 15 (July, 1911), 66-84.

10. Newcomb, *The Indians of Texas,* 224.

11. *Ibid.*

12. Applegate and Hanselka, *La Junta de los Rios,* 13-14 and Victor J. Smith, "Early Spanish Explorations in the Big Bend of Texas," West Texas Historical and Scientific Society *Publication,* No. 2 (1920), 56.

13. Herbert E. Bolton, ed., *Spanish Exploration in the Southwest, 1542-1706,* (New York, 1908), 138-139.

14. Bolton, ed., *Spanish Exploration in the Southwest,* 161-164 and Smith "Early Spanish Explorations in the Big Bend," 57-58.

15. Applegate and Hanselka, *La Junta de los Rios,* 14.

16. J. Charles Kelly, "The Route of Antonio de Espejo Down the Pecos River and Across the Texas Trans-Pecos Region in 1583; Its relation to Texas Archeology," West Texas Historical and Scientific Society *Publication,* No. 7 (1939), 7 and Smith, "Early Spanish Exploration in the Big Bend," 59-68.

17. William E. Connally, ed., *Doniphan's Expedition and the Conquest of New Mexico and California* (Topeka, 1907), fn. 65, 276-282.

18. J. J. Bowden, *Spanish and Mexican Land Grants in the Chihuahuan Acquisition* (El Paso, 1971), 194-208.

19. For a general review of Leaton, see Levitt Corning, *Baronial Forts of the Big Bend: Ben Leaton, Milton Faver and the Private Forts in Presidio County* (San Antonio, 1967), 19-41 and Elton Miles, "Old Fort Leaton: A Saga of the Big Bend," in Wilson Hudson, ed., *Hunters and Healers: Folklore Types and Topics* (Austin, 1971), 83-102.

20. James K. Greer, *Colonel Jack Hays* (rev. ed., Waco, 1974), 217-225; Averam C. Bender, "Opening Routes Across Texas," *Southwestern Historical Quarterly,* 37 (October, 1933), 118-119; Ralph P. Bieber, ed., *Exploring Southwestern Trails, 1846-1854* (Glendale, 1938), 31-38; William A. Goetzmann, *Army Exploration in the American West, 1803-1863* (New Haven, 1959), 227-228, and John S. Ford, "Jack Hays in Texas," typescript, John Salmon Ford MMS, Box 2Q512, University of Texas Archives, 173-174.

21. Samuel Maverick, "Chihuahuan Expedition," typescript, Samuel Maverick MMS, Box 2R210, University of Texas Archives.

22. J. D. Affleck, "History of Jack C. Hays," typescript, J. D. Affleck MMS, Box 2Q402, University of Texas Archives, 748.

23. Greer, *Colonel Jack Hays,* 222.

24. William H. C. Whiting, "Whiting's Diary," *Publication of the Southern History Association,* 10 (1906), 83-85.

25. Goetzmann, *Army Exploration in the American West,* 228-230.

26. M. L. Crimmins, "Two Thousand Miles by Boat in the Rio Grande in 1850; with a Biographical Sketch of the Army Actions of Captain John Love," West Texas Historical and Scientific Society *Publication,* No. 5 (1933), 44-52.

27. Goetzmann, *Army Exploration in the American West,* 227.

28. John R. Bartlett, *Personal Narrative of Exploration and Incidents in Texas, New Mexico, California, Sonora, and Chihuahua Connected with the United States and Mexican Boundary Commission during the Years 1850, 1851, 1852, and 1853* (New York, 1854) and Goetzmann, *Army Exploration of the American West,* Chapter 5, "The Boundary Survey," 153-208.

29. William H. Emory, *Report on the United States and Mexican Boundary Survey Made Under the Direction of the Secretary of the Interior,* 2 vols. in 3, U.S., House of Representatives, 34th Congress, 1st. Session (Washington, 1857), I, 80.

30. *Ibid.,* 81.

31. *Ibid.*

32. John E. Gregg, "The History of Presidio County," (unpublished MA Thesis, University of Texas, 1933), 283-286; Mrs. O. L. Shipman, *Taming the Big Bend: A History of the Extreme Western Portion of Texas from Fort Clark to El Paso* (Marfa, 1926), 26-27; Corning, *Baronial Forts of the Big Bend,* Chapter 3, "Don Milton, Lord of Three Manors," 43-64; Barry Scobee, "Don Milton Faver: Founder of a Kingdom," West Texas Historical and Scientific Society *Publication,* No. 19 (1963), 41-45 and Virginia Madison, *The Big Bend Country of Texas,* rev. ed. (New York, 1968), Chapter 7, "Longhorns to Herefords," 102-125 and Ch. 8 "Cattle are Kings," 126-134.

33. Robert M. Utley, "Longhorns of the Big Bend: A Special Report on the Early Cattle Industry of the Big Bend Country of Texas," typescript, U.S. Department of the Interior, National Parks Service, Region 3 (Santa Fe, 1962), 24-25.

34. Gregg, "The History of Presidio County," 281-282 and Utley, "Longhorns of the Big Bend," 16.

35. Miles, "Old Fort Leaton," 93-94; Carlysle G. Raht, *The Romance of Davis Mountains and Big Bend Country: A History,* edition Texanna (Odessa, 1963), Chapter 7, "1847–," 84-92; and Utley, "Longhorns of the Big Bend," 12-13.

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37. Raht, *The Romance of Davis Mountains,* 127-131; 189.

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THE GEOLOGIC ENVIRONMENT OF THE BOFECILLOS MOUNTAINS, SOUTHEASTERN PRESIDIO COUNTY, TEXAS

Dwight Deal

INTRODUCTION

The Bofecillos Mountains area of Trans-Pecos Texas is an excellent example of a deeply dissected and fairly old volcano. Without some prior knowledge of the geologic history of the Bofecillos, a visitor would have to spend many days walking rugged canyons and mesas, tracing many ancient lava flows and volcanic ash deposits, before accurately visualizing the scene that existed 20 to 30 million years ago. The area was the site of a broad, active volcano with gently sloping sides, probably 15 to 30 km (10-20 miles) in diameter and standing a kilometer (3000 ft) or more above the immediately surrounding terrain. Later vertical displacements along numerous faults, followed by intensive dissection by the Rio Grande and its tributaries, have transformed the gently sloping flanks of the volcano into a jumble of mesas cut by some of the most impressive canyons in Texas. Many solidified lava flows, layers of volcanic ash, and associated sedimentary strata (mostly stream deposits) are exposed in the canyon walls. The Bofecillos Mountains comprise an outstanding natural laboratory where students of geology can physically trace rocks, many representing individual eruptions, in three dimensions to gain an intimate understanding of the construction and development of a major volcano. I know of no other area in Texas where the internal layering of a major volcano is any better exposed.

Probably the most striking thing about the Bofecillos Mountains is the relative abundance of surface water in an otherwise typical Chihuahuan Desert setting. Many seeps, springs, and oases occur in the canyons that cut through the flanks of the old volcano. A combination of internal geologic structure, high porosity and permeability of some of the volcanic units, adequate relief, sufficient rainfall in the higher portions of the Bofecillos Mountains, and an unusual history of land use practices have resulted in an area both where many seeps and springs occur naturally and where man's activities have not subsequently caused them to dry up. Although surface water may run only short distances before disappearing again beneath sandy arroyo sediments, its occurrence in many isolated canyons around the periphery of the Bofecillos volcanic field creates moist and shady settings, often unexpected. These areas provide pleasant and striking contrasts to the drier surroundings, providing dependable water resources for isolated plant and animal communities, and make this study area one of the most pleasant in the Chihuahuan Desert area of West Texas in which to do summer field work. The relative abundance of surface water and the scenic beauty created by the numerous small waterfalls (some over 30 m tall) and spectacular canyons (some with walls rising as much as 400 m) make the canyons of the Bofecillos Mountains one of the most spectacular natural areas in Texas.

The basic resource document describing the geology of the Bofecillos Mountains is a Ph.D. dissertation by John McKnight (1968), a condensed version of which is presented with a geologic map in a publication by the Texas Bureau of Economic Geology (McKnight 1970). I have drawn heavily upon McKnight's work in preparing this report and have walked most of the canyons and mesas while in the area in the summer and fall of 1975 with the Natural Areas Survey field parties. Some minor errors in McKnight's (1970) map were found during field checks, but his map remains more than adequate for the purposes of this study.

This report is designed to provide a comprehensive overview of the geology of the Bofecillos Mountains to be used by both geologists and interested laymen. Although I have attempted to reduce geologic jargon to a minimum, some users of this report may find it helpful to refer to the *Glossary of Geology* (Gary and others 1972). Those interested in a more detailed description of the geology are referred to McKnight (1968). Colored copies of McKnight's (1970) geologic map and geologic cross sections of the Bofecillos Mountains are attached to some copies of this report; additional copies are available directly from the Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas 78712.

PHYSIOGRAPHY

The Bofecillos Mountains are shown on seven fairly recent (1971) 7.5-minute U.S. Geological Survey quadrangle maps: Agua Adentro Mountain, Lajitas, Redford, Redford SE, Santana Mesa, Sauceda Ranch, and the Solitario. The higher summits in the Bofecillos Mountains rise to elevations over 1550 m (5100 ft), standing above rolling mesa country approximately 1300 to 1350 m (4300 to 4400 ft) in elevation. Alternating hard and soft volcanic and sedimentary units in gently dipping to nearly horizontal layers have been eroded to form a stair-step topography dotted with monolithic mountains and unroofed domes created by igneous intrusions. Block faulting has further complicated the topography by creating numerous vertical offsets in the layered rock. The Bofecillos Mountains are bordered to the south by the canyons of the Rio Grande (the cover of this volume is a view southward down a tributary canyon to the Rio Grande floodplain), where elevations below 740 m (2400 ft) occur along the narrow flood plain. The Redford Bolson to the southwest has a valley floor approximately 760 m (2500 ft) above sea level.

Tributaries to the Rio Grande have dissected all sides of the Bofecillos volcanic field. To the east, the volcanic field is fairly abruptly truncated by the largest Rio Grande tributary flowing southward in the area, Fresno Creek (see the companion report on Fresno Canyon, Deal 1976a). Fresno Canyon separates the Bofecillos volcanic field to the west from the Solitario uplift to the east. Two eastward-flowing major tributaries of Fresno Creek (Arroyo Primero and Arroyo Segundo) and the headwaters of Fresno Creek itself drain the east edge of the Bofecillos. Much of the floor of Fresno Creek is below an elevation of 1000 m (3300 ft). Several impressive canyons, also flowing into the Rio Grande, drain the southern and western flanks of the Bofecillos. From southeast to northwest there are: Canyon Madera, Panther Canyon (Cañon Leon), Rancherias Canyon, Tapado Canyon (Oso Cañon), Las Burras Canyon, Auras Canyon (Buzzard Canyon), and Bofecillos Canyon (Cañoncito). The northern portion of the Bofecillos Mountains is drained by northward-flowing tributaries to Torneros Creek. Torneros Creek flows westward, joining the Rio Grande between Presidio and Redford. The major northward-draining tributary to Torneros Creek is Lava Canyon (locally pronounced Lay' va), which heads a short distance north of the Sauceda Ranch headquarters.

All of the major canyons are characterized by steep gradients, spectacular walls, numerous areas containing springs and short segments of flowing streams (see discussion of water resources), dry pouroffs, and perennial waterfalls. Three waterfalls normally flow year-round: Mexicano Falls (Fig. 1) in Arroyo Segundo, Madrid Falls (Fig. 2) in Chorro Canyon (a tributary to Arroyo Primero), and Rancherias Falls in Rancherias Canyon. Panther Falls in Panther Canyon is more intermittent, as are the numerous pouroffs that occur where major drainages cross resistant lava flows and welded ash-flow tuffs.

All the canyons that drain the Bofecillos are rugged, spectacular, and scenic. They can best be traversed on foot or, in most cases, on horseback. Tapado (Oso) Canyon has the most spectacular walls, rising at one point to over 400 m (1200 ft) above the arroyo floor (Fig. 3). The previously mentioned waterfall and pouroff areas are extremely pleasant places to visit. All the major canyons contain areas where erosion has formed scenic rock outcroppings. In addition, wind and water have eroded shelters (Fig. 4) in one yellowish volcanic ash unit (informally referred to as the "Cuevas Amarillas Tuff"; the Tr_{4bp} unit of McKnight (1968 and 1970). This unit is exposed in scenic outcrops (Fig. 5) in most of the westward-flowing canyons (Las Burras, Auras, and Bofecillos), on Wiley Mesa (between Tapado and Rancherias Canyons), and at Ojo Mexicano (at the headwaters of Arroyo Segundo).

McKnight (1968:12-15) described the physiography of the area in detail:

> The Bofecillos Mountains Area is within the Basin and Range physiographic province, and it exhibits desert landforms which are characteristic of the region as a whole. For purposes of orientation and description, it is useful to group these features according to origin into stripped structural surfaces, the Bofecillos Volcano, the fault block zone, breached bolsons, erosional lowlands, and dissected domes (Fig. 6).
>
> **Stripped structural surfaces.** – Highland surfaces of low relief are common, perhaps dominant, features of the landscape to the north and northwest of the Bofecillos Mountains. These are stripped structural surfaces formed by differential erosion of nonresistant tuff and sedimentary rock from more resistant nearly horizontal lava flows and from the Mitchell Mesa ash-flow. In the map area, surfaces of this type include: (1) the Llano Flats, to the northeast, (2) the Primero Flats, to the east-center, and (3) numerous mesa tops. Highland flats did not form elsewhere in the area because of laterally heterogeneous stratigraphy, structural complexity, and active downcutting by Rio Grande tributaries.
>
> **Bofecillos Volcano.** – West of the Llano Flats is a rugged area of discontinuous ridges and steep-sided canyons formed by dissection of the Bofecillos Volcano. Porphyritic and nonporphyritic lava flows ranging from latite to trachyandesite and dipping away from the vents at 1^{o} to 15^{o}, form elongate topographic lobes which overlie pyroclastic material and lower flows. Discontinuous cuestas, developed across the flows, face toward nonresistant pyroclastic material of the main vents. Faults, joints, and dikes, which radiate from the center of the volcano, further accentuate a radial drainage pattern developed on the outward-dipping flows. The

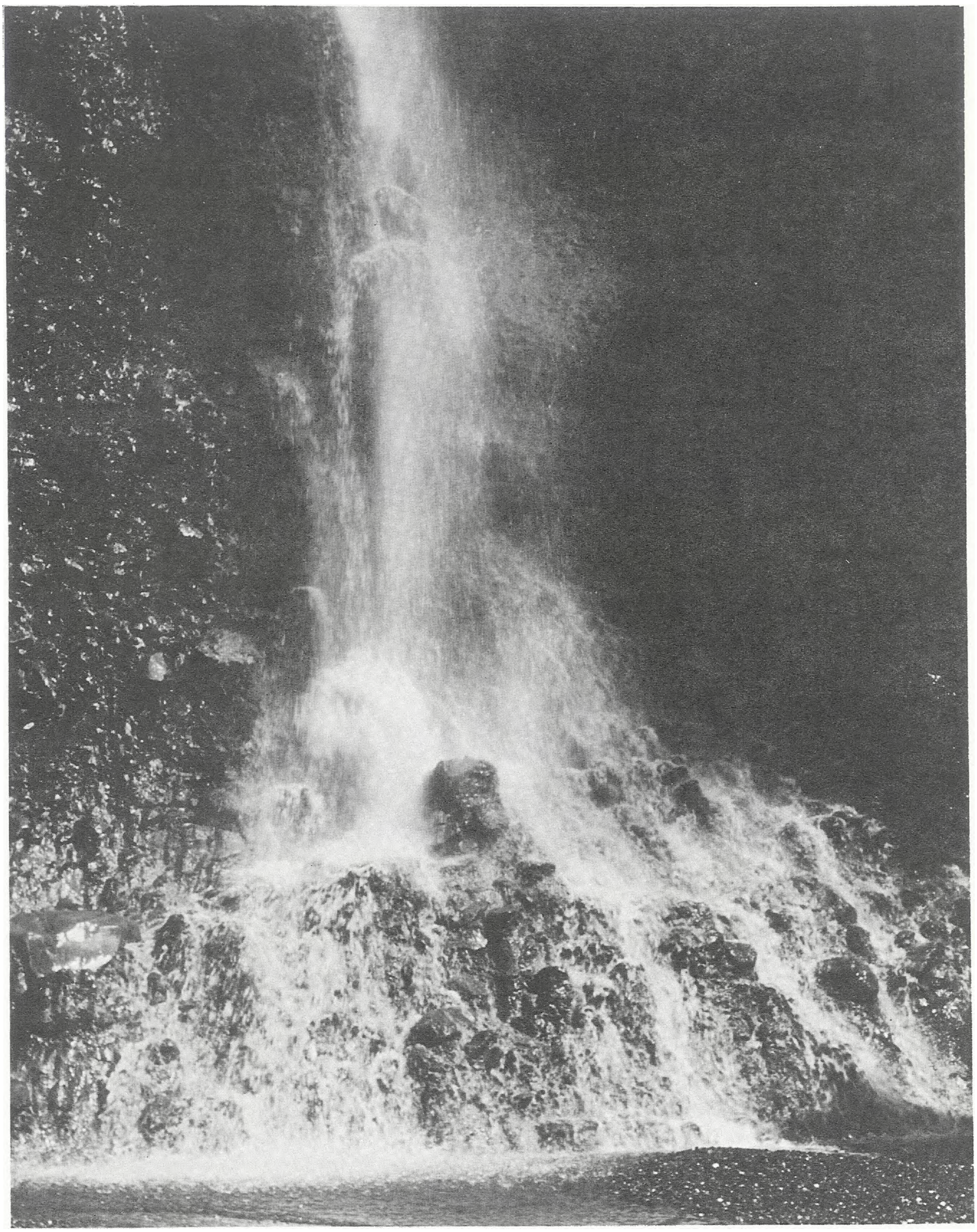


FIGURE 1

Mexicano Falls in Arroyo Segundo.
Photo by Dwight Deal

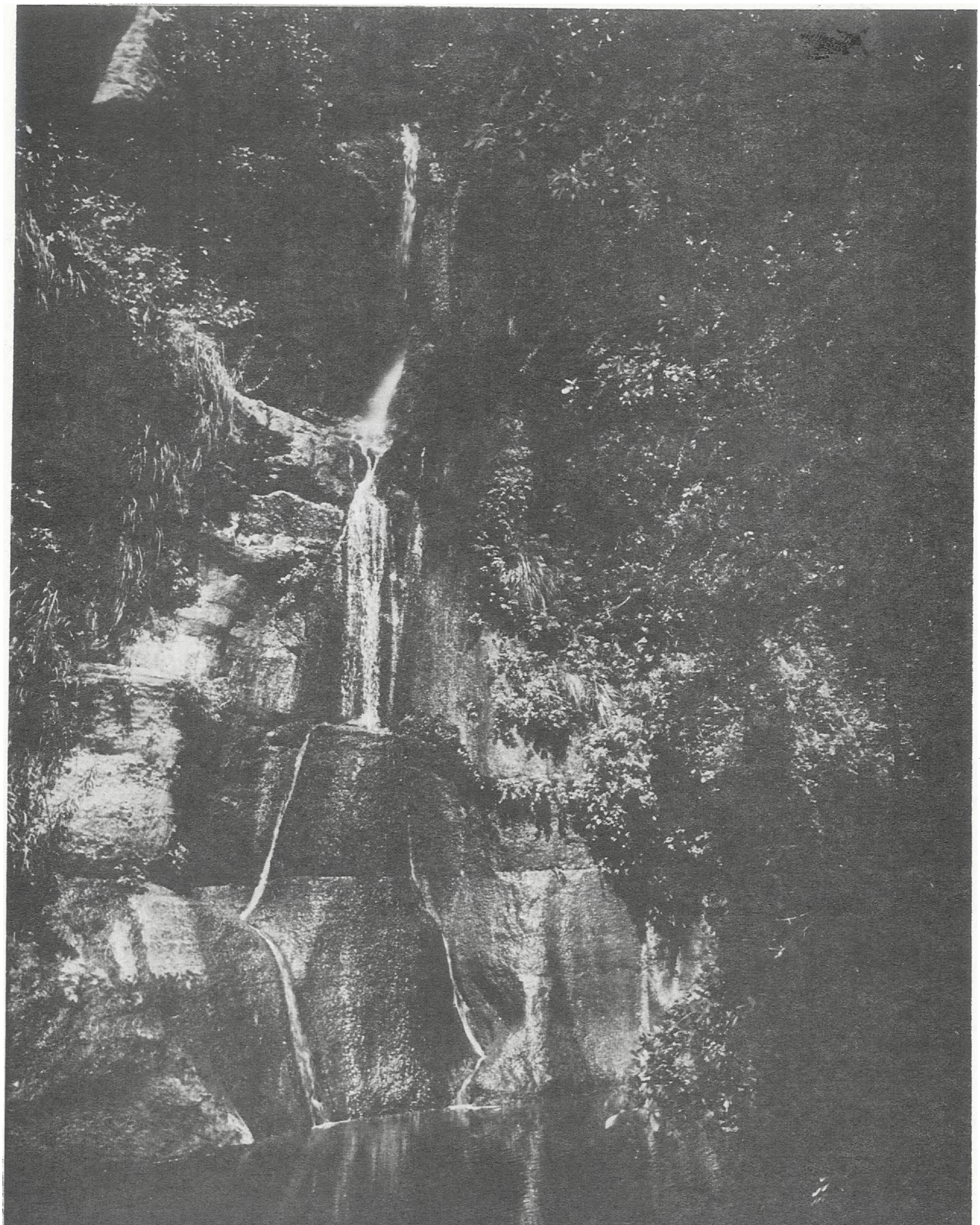


FIGURE 2

Madrid Falls in Charro Canyon, a tributary to Arroyo Primero.
This photograph of the splash pool at the base of the upper falls was taken during low flow (probably minimum flow) conditions in early August, 1975.
Springs also feed this pool–more water flows out than falls in from above.

Photo by Reagan Bradshaw

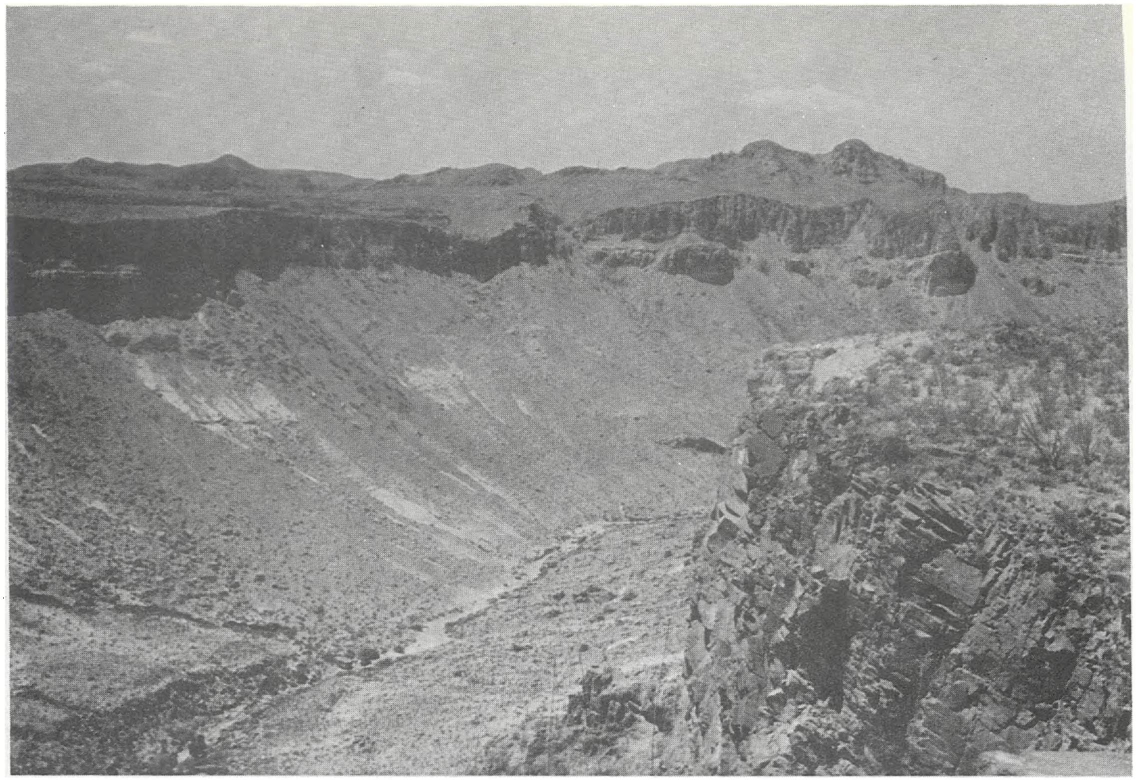


FIGURE 3

Tapado Canyon. Looking upstream from the southwestern end of Upper Wylie Mesa. Approximate elevations above sea level are: canyon floor, 1050 m; top of major cliff, 1300m; highest elevation on skyline, 1435 m. Most of the light colored slope is underlain by volcanic ash. Photo by Dwight Deal

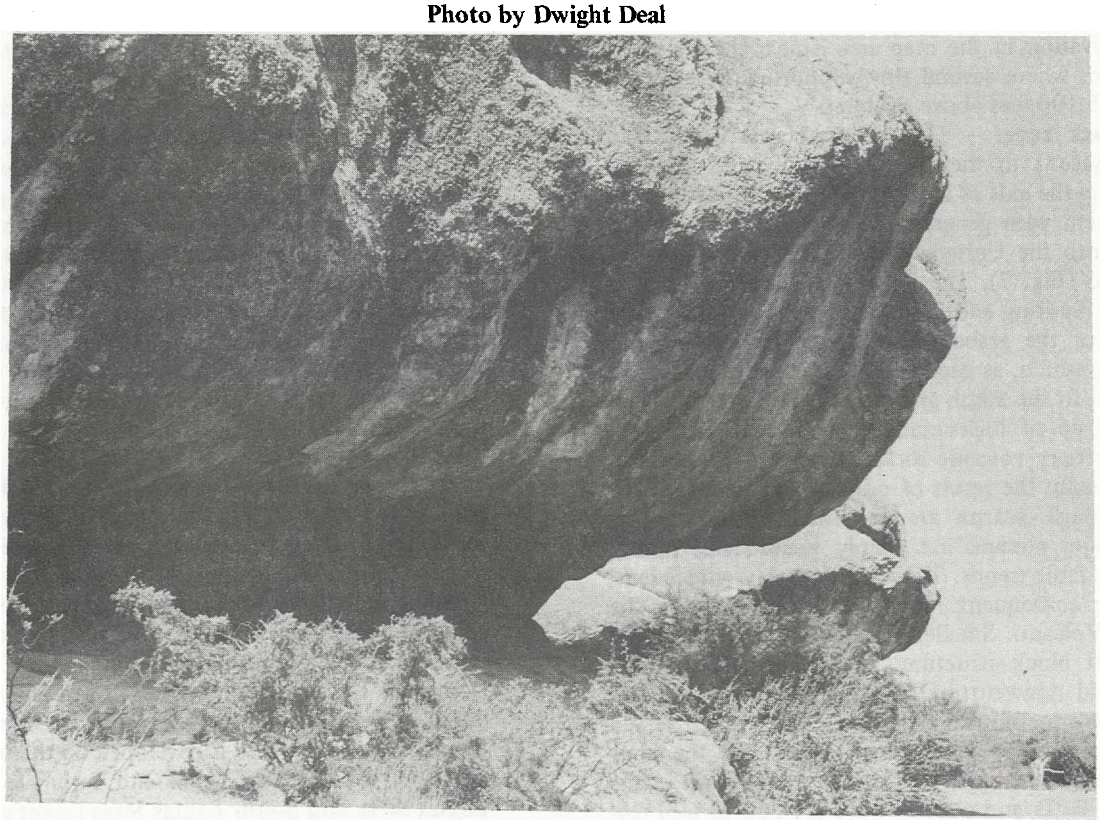


FIGURE 4

Shelters eroded in the "Cuevas Amarillas Tuff." Photo by Reagan Bradshaw

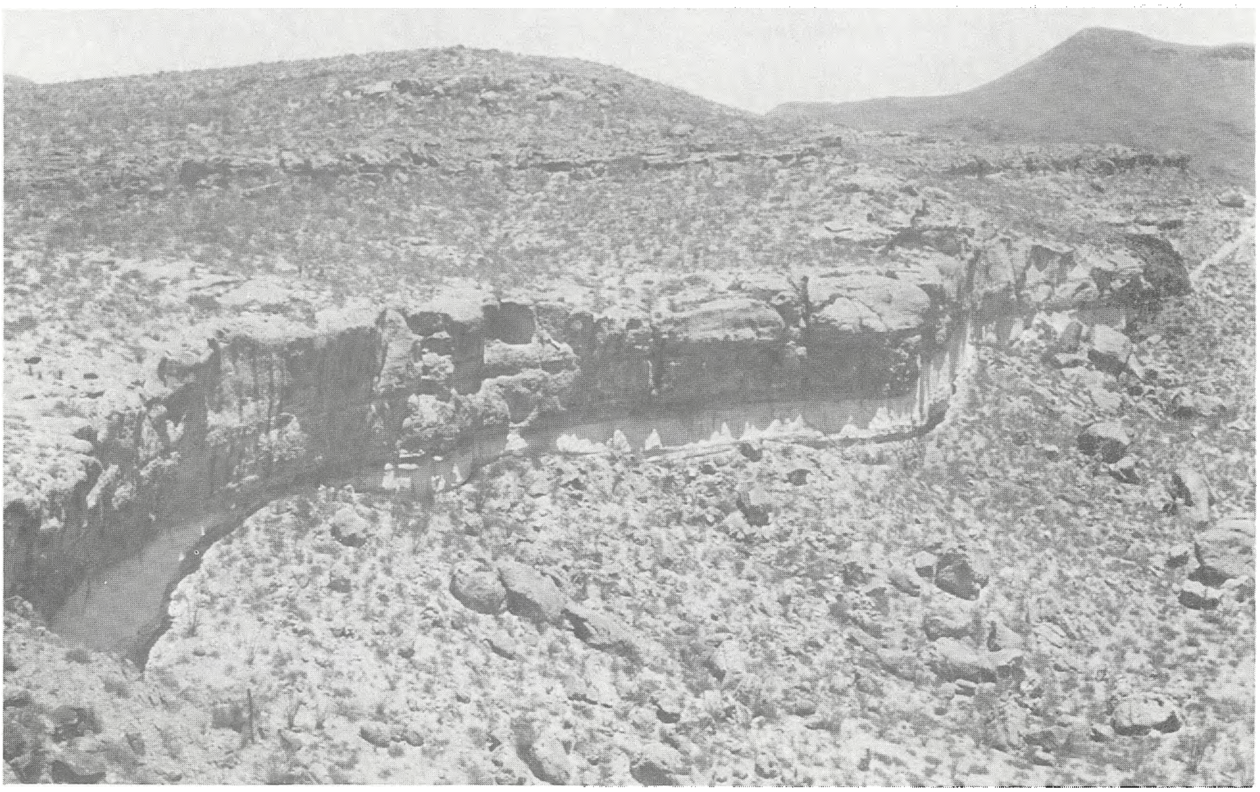


FIGURE 5

**"Cuevas Amarillas Tuff" at the south end of Upper Wylie Mesa.
Photo by Dwight Deal**

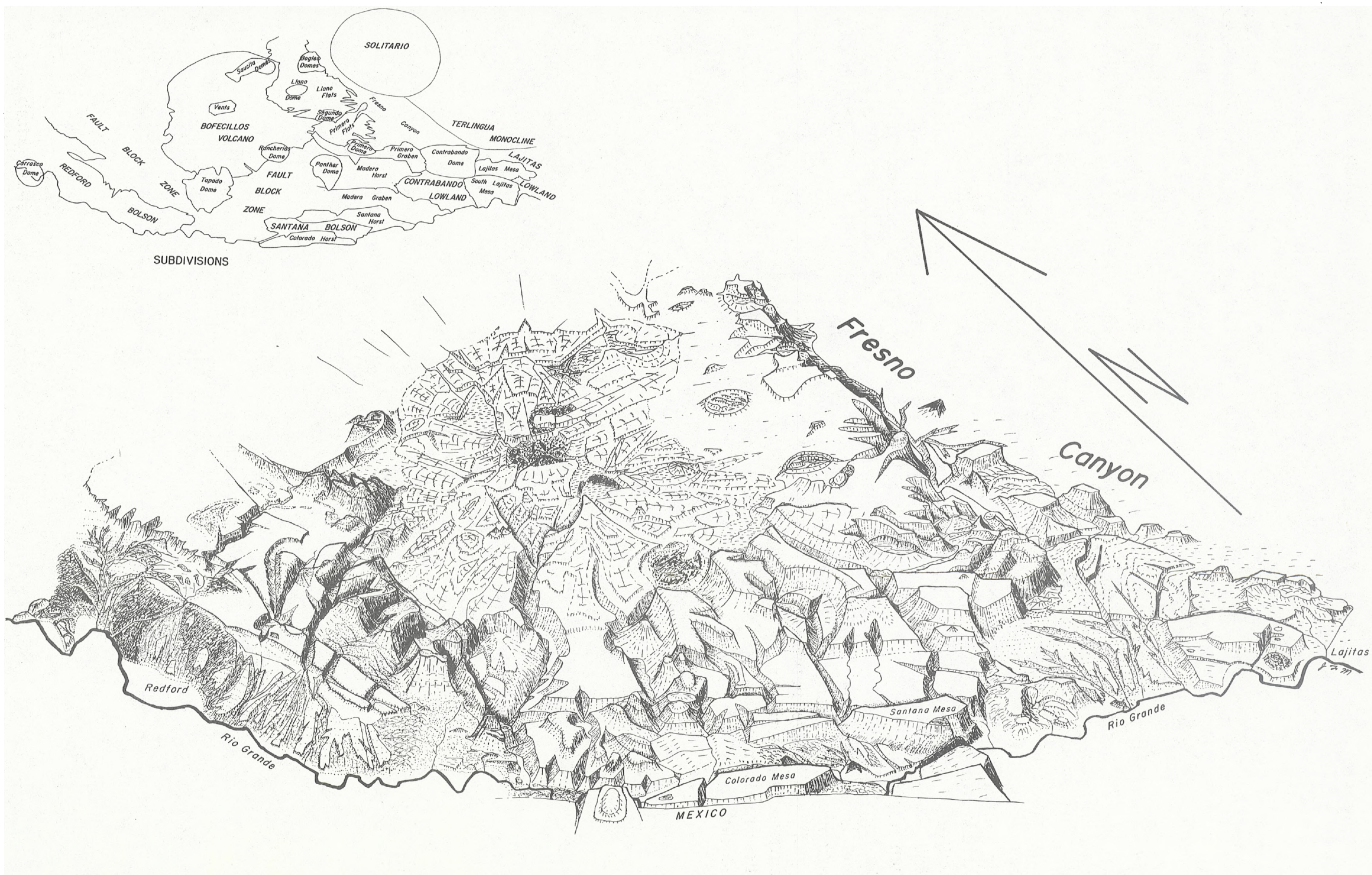
greatest elevation in the map area is near the center of the volcano, where several flow-supported ridges stand more than 5,100 feet above sea level.

Fault-block zone. – The present course of the Rio Grande adjacent to the map area is located approximately along the axis of a compound northwest-trending graben system with generally up-stepping blocks to the northeast into the United States and to the southwest into Mexico (Fig. 7). The lower grabens received sediments after faulting and are now breached bolsons. The remainder of the graben system constitutes the fault block zone, which, as used here, consists of an extensive broken area to the south and west of the Bofecillos Volcano made up of high-standing blocks with relatively resistant Tertiary volcanic rocks exposed at the surface. Relief is mostly the result of original movement on the faults although scarps are modified by differential erosion. Major streams are deeply incised and poorly adjusted to fault trends. They are probably antecedent, maintaining consequent radial courses away from the Bofecillos Volcano. Smaller streams are better adjusted to the fault block structure, and are probably subsequent. Rapid downcutting by streams in this area was controlled by incision of the Rio Grande, which served as a progressively lowering base level, and the zone exhibits the greatest relief of all the subdivisions in the area. Many cliffs and canyon walls are 300 to 600 feet high, and several cliffs are more than 1,200 feet high.

Breached bolsons. – The map area contains two breached bolsons. The Santana Bolson is in the south-central part of the area; the more extensive Redford Bolson lies to the northwest and is a southeastern extension of the much larger Presidio Bolson named by Dietrich (1965). In contrast to the rugged topography of the fault block zone, the bolson areas exhibit moderate relief carved on nonresistant fill; most present streams are incised less than 100 feet below interstream areas. Gravel-capped pediment surfaces are common and slope toward the Rio Grande, which adjoins the lower part of the Santana Bolson and occupies the axial part of the Redford Bolson. Drainage is generally subparallel toward the Rio Grande.

Erosional lowlands. – The southeastern part of the map area is mostly a lowland developed in relatively nonresistant upper Cretaceous and Tertiary sedimentary rock where resistant Tertiary lava flows higher in the section have been removed by erosion. Removal of the resistant rock has progressed to the greatest extent on or adjacent to structural highs: the Contrabando Lowland is developed on laccolithic domes including Contrabando Dome; the Lajitas Lowland is developed on homoclinally dipping beds south of the Terlingua Monocline; the Fresno Canyon lowland is developed on the west-dipping flanks of the Solitario Dome and Terlingua Monocline. Lajitas Mesa and South Lajitas Mesa lie between and are structurally lower than the Contrabando and Lajitas Lowlands.

FIGURE 6
Physiographic Diagram of the Bofecillos Mountains
(From McKnight 1968: Fig. 4)



Dissected domes. – Intrusions are abundant in the map area, and many have domed the overlying strata. Subsequent erosion has resulted in the formation of concentric cuestas with striking annular drainage. Such breached domes are found throughout the area included within the physiographic subdivisions listed here.

ACCESS

Vehicular access to the area is limited. None of the roads are paved, and, even under the best of conditions, the combination of a 4-wheel-drive vehicle and a half-day's walk is necessary to reach much of the area. A graded county road provides access through the northern part of the Bofecillos Mountains. It extends from Ranch Road 170 between Presidio and Redford to Sauceda Ranch (the Big Bend Ranch headquarters of the Diamond A Cattle Company) and then northward through Wire Gap to Marfa. During the rainy season (July, August, and September), this road is usually in poor condition and often is not passable in passenger cars. Big Bend Ranch maintains a fairly extensive network of ranch roads in the central and eastern part of the Bofecillos Mountains. These roads provide access to the central vent area of the Bofecillos volcanic field and to the summits of many of the mesas in the southern and eastern parts of the area. The ranch roads are minimally maintained for basic ranch operations and are usually traversed on horseback or in a 4-wheel-drive vehicle. The historic Marfa-Lajitas highway passes southward through Fresno Canyon on the eastern border of the Bofecillos volcanic field. Although this was once a county-maintained road, it has reverted to private ownership and is only occasionally maintained and used. Under normal conditions the steep rocky grades and loose sand require a 4-wheel-drive vehicle, especially to traverse the road from south to north. It is possible to follow this old road from its junction with the graded county road east of Sauceda Ranch headquarters, southward through Fresno Canyon to the now-abandoned Fresno (mercury ore) Mine, where a county-maintained road continues on to Lajitas and paved Ranch Road 170. Ranch Road 170, referred to as the "River Bend," follows the north side of the Rio Grande along the southern margin of the Bofecillos volcanic field. This road runs from Presidio to Big Bend National Park. The topography close to the Rio Grande is so rugged that dirt roads extend for only a short distance northward from it into the Bofecillos Mountains before becoming impassable. Most access from the south is limited to foot or mounted travel.

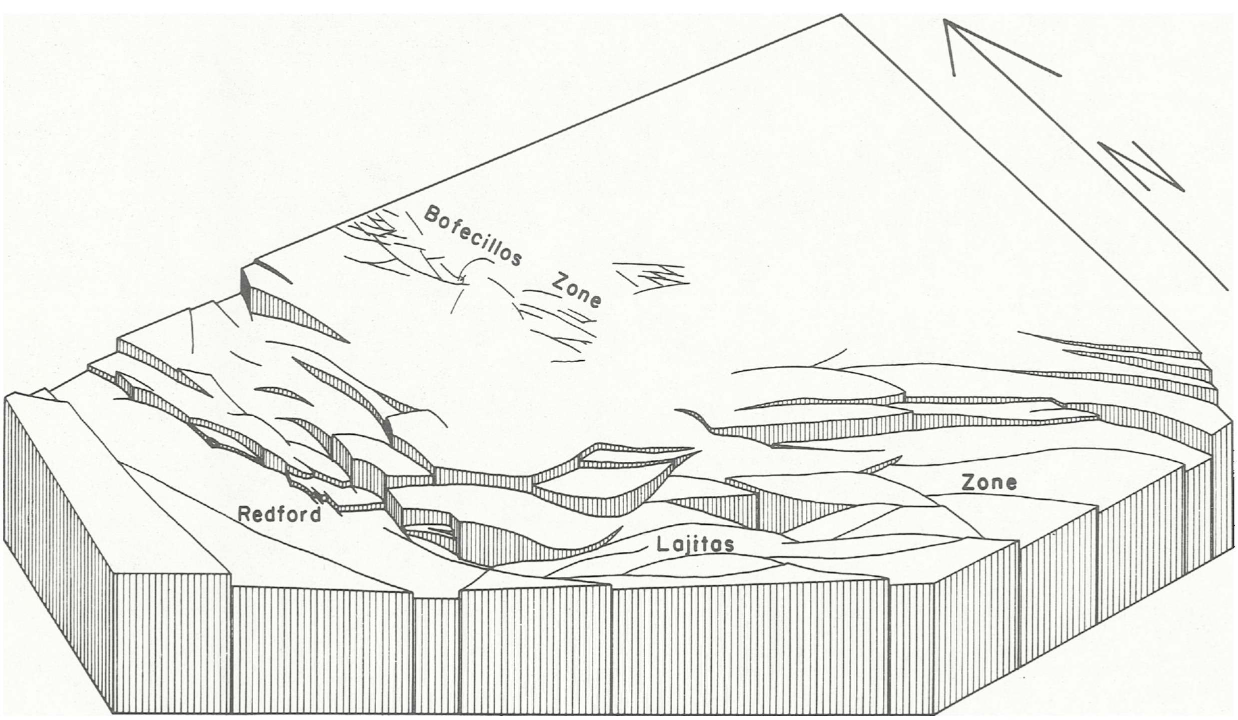


FIGURE 7

Pattern of Faults in the Bofecillos Mountains Area.
Block faults with as much as 600 m of throw in the Redford-Lajitas fault zone contrast sharply with faults of slight offset in the Bofecillos fault zone.
(From McKnight 1968: Fig. 16)

CLIMATE

No climatic records have been kept within the Bofecillos Mountains study area. A U.S. Weather Bureau Station was in operation in Presidio from 1957 to 1969. Dietrich (1965:14-23) presented a fairly elaborate discussion of both regional and local climate of the Presidio and Bofecillos Mountain area. He went into a rather detailed discussion of the Koppen classification of climate, analyzed the climatological data from 27 meteorological stations in Trans-Pecos Texas (Fig. 8). The data from the eight

FIGURE 8

Interior of the Solitario. Rim escarpment in background. Photo by Dwight Deal

U.S. Weather Bureau stations is shown in Table 1, arranged in order of decreasing station elevation to emphasize the high degree of correlation between elevation and temperature. Mean annual precipitation increases from west to east at stations with comparable elevations and also increases with an increase in elevation. Dietrich (1965:16) applied the Koppen classification to each of these stations and concluded that they all have a dry climate. Four stations have a steppe (*BS*) climates. The three higher stations (Mount Locke, Chisos Basin, and Alpine) have a cold steppe (*BSk*) climate, and the easternmost station, Fort Stockton, has a hot steppe (*BSh*) climate. The other four stations have desert (*BW*) climates. Van Horn and El Paso are classified as having cold desert (*BWk*) climates, and Balmorhea and Presidio are classified as having hot desert (*BWh*) climates. Dietrich (1965:16) concludes:

> The steppe climate probably extends to the highest peaks in the mountains of Trans-Pecos Texas. Mount Locke (elevation 6790 feet) has the highest mean annual precipitation and the lowest boundary precipitation value of the eight stations. Its steppe (*BS*) classification would remain unchanged if the station received one-third more precipitation.

Data from those eight climatological stations (Table 1) show that the mean temperature decreases one to one and one-half degrees C per 100-m (two to three degrees F per 1000 ft) increase in elevation.

Dietrich also considers data from 19 weather stations maintained by the International Boundary and Water Commission (Table 2; Fig. 9) and had plotted the station elevation for all 27 stations against the mean annual precipitation (Fig. 9). This data indicates that both geographic position and elevation obviously influence precipitation. At stations near the same longitude, the mean annual precipitation increased five to seven cm per 100 m (2-3 in per 1000 ft) increase in elevation, and at stations near the same

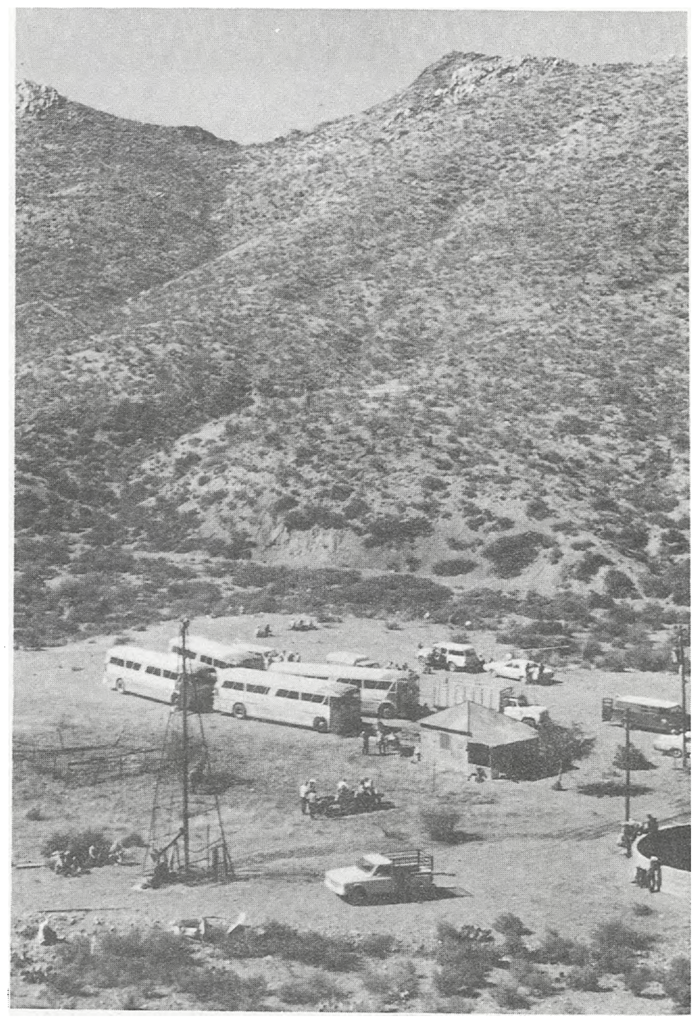


FIGURE 9

The West Texas Geological Society at Tres Papalotes in 1972. The trip to view the geological wonderland in the center of the Solitario attracted professional geologists from across the nation and was the second time the Society brought large Greyhound buses into the area. Big Bend Ranch expended considerable effort to prepare the road, which stayed in good condition only until the next rain. Photo by Dwight Deal

Table 1 — Climatological data, eight U.S. Weather Bureau stations in Trans-Pecos Texas.
(from Dietrich 1965: Table 2)

STATION		TEMPERATURE								PRECIPITATION		KOPPEN CLASSIFICATION	
		Extremes				Means							
		High		Low									
Name	Elevation (ft. above MSL)	°F	Year	°F	Year	Jan. (°F)	July (°F)	Annual (°F)	Record period *	Mean annual (inches)	Record period *	r = o.44t - 3	Climate symbol
Mt. Locke	6790	98	1962	–10	1962	41.7	70.0	57.2	†1945-63	18.72	1945-63	25.17	*BSk*
Chisos Basin	5300	102	1958	– 3	1949	48.9	74.8	63.2	†1948-63	15.19	1949-63	27.80	*BSk*
Alpine	4433	106	1932 1936	– 2	1933	46.7	77.4	63.2	WBN	15.42	WBN	27.80	*BSk*
Van Horn	4050	108	1951	– 7	1962	44.3	80.4	62.8	†1942-63	9.52	1939-63	27.63	*BWk*
El Paso	3918	109	1960	– 8	1962	43.9	81.4	63.6	WBN	7.89	WBN	27.98	*BWk*
Balmorhea	3225	112	1939	– 9	1933	47.3	81.1	65.1	WBN	12.68	WBN	28.64	*BWh*
Ft. Stockton	2995	114	1907 1934	– 7	1911	47.6	82.2	66.1	†1931-60	16.45	†1931-60	29.08	*BSh*
Presidio	2582	117	1957 1960	+ 4	1962	49.8	86.5	69.5	WBN	8.31	WBN	30.58	*BWh*

*WBN: Weather Bureau normal for 1931-1960.
†: Some records missing.
Data sources. — Normals (WBN) from U.S. Weather Bureau (1962, p. 4); other means calculated from data in the office of the State Climatologist, Robert B. Mueller Airport, Austin, Texas.

Table 2 – Mean annual precipitation and geographic data, 27 stations in Trans Pecos Texas. (from Dietrich 1965: Table 3)

STATION					PRECIPITATION	
Name	Symbol *	Location Lat.	Location Long.	Elevation (ft. above MSL)	Record period **	Mean annual (inches)
International Boundary and Water Commission						
American Dam	1	31°47'	106°32'	3,730	1938-61	7.49
Fabens-Guadalupe Bridge	2	31°26'	106°08'	3,610	1940-61	7.12
Fort Quitman	3	31°06'	105°36'	3,430	†1937-61	8.00
Adobes	4	29°46'	104°34'	2,550	1950-61	8.60
Presidio	5	29°34'	104°23'	2,550	1950-61	6.21
Quebec Ranch	6	30°31'	104°24'	4,600	1949-61	11.28
Bloys Camp	7	30°33'	104°07'	5,650	†1941-61	19.11
Kerr Mitchell Ranch	8	30°13'	104°00'	4,450	†1941-61	11.71
Loma Vista Ranch	9	30°13'	103°48'	5,450	†1941-61	12.01
H. T. Fletcher Ranch	10	30°12'	104°16'	5,100	†1939-61	14.49
Sauz Ranch	11	30°10'	104°12'	4,880	1940-61	13.68
A. L. Baugh Ranch	12	29°52'	104°02'	3,820	1942-61	10.16
H. M. Greenwood	13	29°48'	104°13'	4,000	1941-61	12.54
O2 Ranch	14	29°51'	103°45'	3,780	†1914-61	12.76
Johnson Ranch	15	29°01'	103°23'	2,050	†1933-61	7.54
Persimmon Gap Ranger Station	16	29°40'	103°10'	2,900	†1948-61	8.21
Steve Stumberg Ranch	17	30°11'	102°53'	4,300	†1943-61	12.52
Arvin and Harkins Header	18	30°27'	102°26'	3,400	1949-61	13.02
Arvin and Harkins Headquarters	19	30°27'	102°20'	2,930	1949-61	11.77
U.S. Weather Bureau						
El Paso	E	31°48'	106°24'	3,918	WBN	7.89
Van Horn	V	31°02'	104°51'	4,050	1939-63	9.52
Presidio	P	29°33'	104°24'	2,582	WBN	8.31
Mt. Locke	L	30°22'	104°00'	6,790	1945-63	18.72
Balmorhea	B	31°00'	103°41'	3,225	WBN	12.68
Alpine	A	30°22'	103°39'	4,433	WBN	15.42
Chisos Basin	C	29°16'	103°18'	5,300	1949-63	15.19
Fort Stockton	S	30°52'	102°55'	2,995	†1931-60	16.45

*Station identification on map (Fig. 2) and diagram (Fig. 3)
**WBN: Weather bureau normal for 1931-1960.
†: Some records missing.
Data sources. – International Boundary and Water Commission stations (I.B.C, 1961).
U.S. Weather Bureau stations: normals (WBN) from U.S. Weather Bureau (1962, p. 4); other means calculated from data in the office of the State Climatologist, Robert B. Mueller Airport, Austin, Texas.

elevation, the mean annual precipitation increases from west to east.

Dietrich (1965:21) calculates that with no change in the mean annual temperature, 85% increase (18 cm or 7 in) in the mean annual precipitation at Presidio would be required to change the classification from hot desert climate (*BWh*) to steppe. He went on to approximate temperature gradients in the area from the regional data and calculated that the boundary between desert and steppe climate should occur about 1500 m (4900 ft) above mean sea level. If he is correct, then the desert-steppe boundary is near the tops of the higher peaks in the Bofecillos Mountains and the Solitario.

Dietrich (1963:22-23) also presents a good discussion of the effect of surface water:

> The U.S. Weather Bureau collects temperature data from a uniform height above the surface site selected to give data representative of large areas. These data accurately reflect the macroclimate, the climate above a thin boundary layer of air near the surface. The microclimate, the climate within the boundary layer a few inches to a few feet thick, is highly variable.
>
> Where the macroclimate is near the borderline separating steppe and desert climates, the effects of factors that modify the microclimate are dramatic. Surface attitude and texture are two important factors that affect surface temperature, and therefore the microclimate. South-facing slopes, more nearly normal to the sun's rays than north-facing slopes, or the floors of narrow-walled canyons, receive more abundant energy per unit area and are a little hotter and dryer. Soil on an open surface is hotter and drier than the soil in pockets between large boulders because the boulders shield the small pockets from direct solar radiation during part of the day. Because of these small differences, grass grows on north-facing or boulder-strewn surfaces at elevations where south-facing or open surfaces are barren. A tank, a spring, or flowing stream modifies the climate in a small area. Evaporation lowers the air temperature and increases the humidity in the immediate vicinity of the water.

These microclimate effects are particularly important in the canyons that dissect the ancient volcano.

PREVIOUS AND RELATED WORK

The 1857 Mexico-U.S. Boundary Survey headed by Emory passed through this area. One of the members of that survey was C. C. Parry (1857), who wrote the first report on the geology of the Bofecillos Mountains. Parry's report was of necessity a reconnaissance and concentrated on descriptions of the striking physiography along the course of the Rio Grande, including the southern part of the Bofecillos Mountains. He described the bolson and pediment development in the basins along the river and the igneous rocks which are exposed in the canyons.

Kimball (1869) traveled southeastward through Presidio as part of a reconnaissance through west Texas and northern Chihuahua. He crossed the Rio Grande Valley and explored the drainage of the Rio Conchos, describing fossils that demonstrated much of the limestone in the area was of Cretaceous age. He noted the overlying volcanic ash falls and lava flows, which are now known to be of Tertiary age, and incorrectly considered them to be Cretaceous, inferring a metamorphic, rather than a volcanic, origin for them.

In the late 19th Century, the discovery and development of mercury deposits along the Terlingua Monocline brought many geologists into the area. A good summary of the development of the mercury (cinnabar) resources in the Terlingua District, east of the Bofecillos Mountains, is presented by Daugherty (1972, *in* Deal 1975a: Appendix 3). The early history of exploitation, distribution, and origin of the deposits is described in reports by Blake (1895), Turner (1900, 1906), Spalding (1901), B. F. Hill and Phillips (1902), R. T. Hill (1902), B. F. Hill (1903), Phillips (1905), Kirk (1905), and Udden (1907, 1918). Udden's 1907 "Sketch of the Geology of the Chisos Country" was particularly significant to the study of the Bofecillos Mountains and Fresno Canyon area because it fitted the Terlingua District into its regional geological setting. More detailed works by Ross (1935, 1937, 1941) and by Yates and Thompson (1959) further explain the geologic factors controlling ore implacement and further describe the regional stratigraphy and structure of the area.

The Solitario, immediately east of the Bofecillos Mountains area and Fresno Canyon, received some mention in mineral reports on the Terlingua District. Further information on the Solitario and on Fresno Canyon are contained in companion reports by Deal (1976a, 1976b).

Maps and reports, mostly sponsored by the University of Texas Bureau of Economic Geology (Sellards and others 1933; Goldich and Elms 1949; Seward 1950; Erickson 1953; Lampert 1953; McCarthy 1953; Moon 1953; Rix 1953; Zinn 1953; Dietrich 1954, 1964, 1965; McAnualty 1955; Amsbury 1958: and Ramsey 1961), carried Tertiary volcanic stratigraphy from the north and northwest, providing the basis for McKnight's (1968) work on the Bofecillos Volcano itself.

A geologic report on the Big Bend National Park, immediately southeast of the area (Maxwell and others 1967), is a detailed study of the geologic history of that area and allows McKnight (1968) to relate the events of the Bofecillos Volcano to the events occurring within the National Park.

The International Boundary and Water Commission (1955) prepared a series of geologic strip maps at a scale of 1:50,000 along the Rio Grande, extending upstream from Del Rio to a point four miles upstream from Lajitas beginning about at the mouth of Fresno Canyon at the southeastern edge of the Bofecillos Mountains. Arenal (1964) made a geologic reconnaissance map on the Mexican side of the Rio Grande, south of the Bofecillos, in a study of coal and lignite deposits in rocks of Upper Cretaceous age. J. A. Wilson and his students (1952, *in* Maxwell and others 1967) have collected vertebrate fossils from locations outside but nearby the Bofecillos Mountains. Twiss and DeFord (1967) published some potassium-argon age dates from the rimrock country northwest of the study area, and Wilson and others (1968) compiled more detailed information on the stratigraphic succession, potassium-argon dates, and vertebrate faunas of the same area.

As previously mentioned in the introduction to this report, John McKnight spent many months in the Bofecillos Mountains area in 1963, 1964, 1965, and 1966 collecting more than 2000 rock samples, 181 of which were studied in microscopic detail. He also studied an additional 164 microscopic thin sections of rock samples collected in the Bofecillos Mountains area in 1959 and 1960 by Dietrich and Maxwell. McKnight's (1968) Ph.D. dissertation and subsequent condensation (McKnight 1970) are extensively quoted in this report and have provided the basic background information for the geology of the Bofecillos Mountains. I worked in this area during the summer and fall of 1975 with field teams of the University of Texas Natural Areas Survey, an interdisciplinary group that not only worked in the Bofecillos Mountains, but also in the adjacent Solitario, Fresno Canyon, and Colorado Canyon areas. These adjacent areas are described in companion volumes (Deal 1976a, 1976b, 1976c).

GEOLOGIC HISTORY

Introduction

In this report we are primarily concerned with the recent geologic history of the area: the development of the Bofecillos Volcano and its subsequent dissection by erosion. The volcano was built upon a very complicated sequence of older Paleozoic and Cenozoic sedimentary rocks. It is only one of many volcanic centers that existed throughout the southwestern United States in early Tertiary time, stretching from Mexico through the Big Bend area and southwestern New Mexico into Arizona and Nevada. This was a time of major volcanic activity and, in the immediate vicinity of the Bofecillos Mountains, was associated with a series of eruptive events in Big Bend National Park, the Chinati Mountains, and the Davis Mountains, and with other vents to the south in Mexico.

The building of the Bofecillos Volcano was one of the last major volcanic events to occur in southeastern Presidio County. The volcano itself probably stood more than 1 km (3000 ft) above its surroundings and, immediately following the time of most active eruption, stood as a gently sloping cone, probably about 25 km (15 miles) in diameter, composed of alternate layers of solidified lava flows, ash deposits, and associated water-deposited sedimentary rocks. The center of the Bofecillos Volcano is in the Bofecillos Vent area, approximately 6.5 km (4 miles) west and slightly south of the Sauceda Ranch headquarters. As eruptions became less frequent and of smaller magnitude, a number of igneous intrusions failed to reach the surface and caused a series of small domal uplifts to form on the western and southern flanks of the volcano: Saucita (misspelling of Sauceda), Bolges, Llano, Segundo, Primero, Panther, Rancherias, and Tapado Domes (see the geologic map of McKnight 1970). Other domes on the northern flank of the Bofecillos Volcano are described by Dietrich (1966).

Erosion has subsequently dissected that volcano, exposing its internal structure. The Rio Grande and side streams tributary to it have deposited a sequence of Quaternary sediments (Deal 1976c).

Paleozoic Stratigraphy and Mountain Building

The older rocks known to underlie the Bofecillos Volcano are those of Lower Paleozoic age. The Solitario Dome just to the east of the Bofecillos Mountains, across Fresno Canyon, exposes those rocks. They are described in more detail in the companion volume on the Solitario (Deal 1976a) and in the works of Herrin (1958), Wilson (1954), West Texas Geological Society Field Guide Books (1965, 1972), and Corry (1972).

Briefly, from oldest to youngest the Paleozoic section consists of the following: the Dagger Flat Formation (sandstone) of Cambrian age; the Marathon Formation (black siliceous shale, sandstone, sandy limestone, dark chert, and blue limestone), the Fort Peña Formation (limestone, sandy limestones, and cherts), the Woods Hollow Shale (fine-grained shale with some flaggy sandstones and siltstones), and the Maravillas Chert (black bedded chert with some limestone lenses and some intraformational conglomerates), all of Ordovician age; and the Caballos Novaculite (white chert) of Devonian-Mississippian age. The two chert units (the Maravillas Chert and the Caballos Novaculite) are prominent ridge-formers within the Solitario. The total thickness of the measured Paleozoic section in the Solitario is approximately 2600 m.

A major series of mountain-building events followed the deposition of the Paleozoic rocks in Late Pennsylvanian-Early Permian time (Flawn and others 1961:188; Deal 1976a). These events were part of what is called the Ouachita Orogeny, a major and continuous band of folding that extended over much of the southern United States, comparable in age and type to the Appalachian Mountain structures of the eastern United States. The axis of the Ouachita fold belt in the Solitario-Marathon region extends northeast to southwest with thrusting and compression from the southeast to the northwest. These intensely folded, distorted, faulted rocks certainly underlie the Bofecillos Volcano.

Cretaceous Stratigraphy and Mountain Building

Following the time of intense deformation during the Ouachita mountain-building period, the Bofecillos Mountains area experienced a considerable time of erosion. The area was above sea level, and running water reduced what must have been a magnificent mountain range to a nearly flat, relatively featureless plain. Because this was largely a time of erosion, much of the geologic history of that time of erosion has been lost. In early Cretaceous time (about 145 million years ago) the southeastern Presidio County area was submerged once again beneath ocean waters, and a sequence of massive limestones was deposited in the northward extension of the Mexican geosyncline. These rocks are described in more detail in the companion volume on Fresco Canyon (Deal 1976a) and in the works of McKnight (1968) and Maxwell and others (1967). Approximately 1.2 km of thick, flat-lying limestones were deposited in the Cretaceous seas. Following the deposition of those rocks, the main mountain-building episode of the North American Cordillera, known as the Laramide Orogeny, again folded and faulted the area.

Doming of the Solitario

The Laramide mountain-building period was followed by a series of igneous intrusions, in turn followed by a series of volcanic eruptions which covered the landscape with a sequence of lava flows and ash deposits.

The first evidence of volcanic activity in southeastern Presidio County was, in early to middle Tertiary time (probably Eocene or Miocene, probably 20 to 45 millions years ago) (Fred McDowell, oral communication, March 1976), the intrusion of magma into the base of the Cretaceous limestone sequence. Then, as the orogeny progressed, the Solitario Dome was formed. Similar structures may be hidden beneath the volcanic material that issued from the Bofecillos volcanic vent.

After the development of the Solitario Dome and prior to the deposition of the Tertiary volcanic rocks in the area, the structure known as the Terlingua-Solitario Monocline (Maxwell and others 1967) was formed. This structure extends northwestward into the southeastern edge of the Bofecillos volcanic field and is described in more detail in the companion report on Fresno Canyon (Deal 1976b). It has been the site of extensive geologic investigations and the commercial production of cinnabar (mercury ore).

Pre-Volcanic Regional Tectonic Setting

McKnight (1968:117) describes the geologic setting that existed before the eruption of the Bofecillos Volcano as follows:

> As shown in Figure 10, most or all of the map area is underlain at depth by folded and faulted Paleozoic strata of the northeast-trending frontal zone of the Ouachita structural belt (Flawn and others 1961:100); these strata are exposed in the Marathon region (King 1937) and in the Solitario (Herrin 1958). After a period of Mesozoic emergence, dominantly marine Cretaceous strata were deposited with angular unconformity on the Paleozoic rocks. During Laramide deformation intense folding and faulting occurred along north-northwest trends about 35 miles (56 kilometers) southwest of the map area in the broad, but as yet poorly delimited, Chihuahua Tectonic Belt, and about 40 miles (65 kilometers) to the northeast in a belt a few miles wide including the Del Norte-Santiago Mountains and the Sierra del Carmen (Maxwell and others 1967). Between these two strongly deformed areas is a relatively stable block with generally broad folds and normal faults extending from the Coahuila Platform southeast of the map area to the Diablo Platform to the northwest; whether the two platforms were continuous or separate structural elements during Laramide deformation is not known (Dietrich 1965:200). Local Laramide structures extending into or adjacent to the map area are the Terlingua Monocline to the east, fault blocks at the north end of Mesa de Anguila to the southeast (Maxwell and Dietrich 1965:32), and relatively gentle deformation to the northwest (Dietrich 1965:207); in the erosional lowlands, an angular unconformity with as much as 10 degrees of dip between upper Cretaceous strata and the Jeff Conglomerate indicates gentle Laramide folding.
>
> After the development of Laramide structures, the map area and much of the region to the northwest were structurally stable while laterally planing streams eroded much of the region to a pediment mantled by the Jeff Conglomerate. Probably all of the map area was thus planed to base level except for the Laramide Terlingua Monocline which remained topographically high. Eruptive activity followed the deposition of most of the

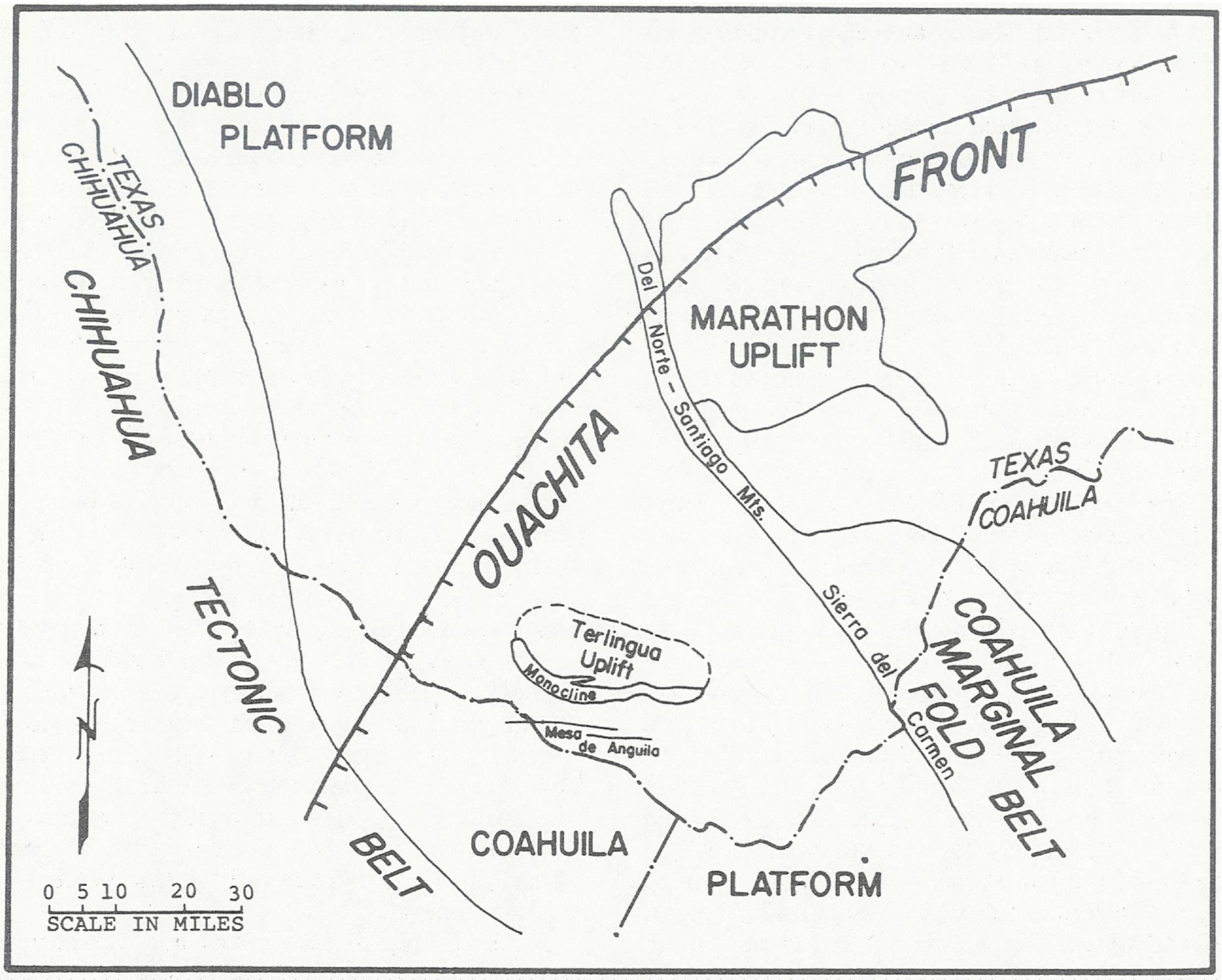


FIGURE 10

Pre-volcanic regional tectonic setting in the Big Bend region and adjacent Mexico. (From McKnight 1968: Fig. 13)

Jeff and the conglomerate is, therefore, essentially post-orogenic.

TERTIARY VOLCANIC STRATIGRAPHY

Introduction

To understand the distribution of rocks that are associated with the Bofecillos Volcano, it is helpful to have an understanding of the cause of volcanic eruptions. Why do volcanoes erupt?

Heat first accumulates in local areas within the earth's crust, largely due to the decay of radioactive materials. As a result of this heat, rocks eventually melt and chambers of molten rock (known as magma chambers) develop. Mountain-building activities may increase the pressure on the magma chambers and, in addition, since molten rock takes up more volume and is less dense than solid rock, gravity helps force the magma upward toward the surface. The molten rock normally follows preexisting zones of weakness and, if it quietly flows out on the surface, lava flows result. These later cool and solidify, forming a wide variety of volcanic rocks, usually classified on the basis of their mineral and chemical composition. Most lava flows associated with the basaltic rocks of the world's ocean basins result from quiet eruptions and build broad, gently-sloping volcanic mountains of dark basaltic rocks (Hawaii is a classic example). Most of the volcanic eruptions associated with continental areas are much more violent. The volcanoes of Trans-Pecos Texas were built by fairly violent eruptions and probably developed the steeper-sided, more "classical" shape seen in Mounts Vesuvius and Fujiyama.

Why are some eruptions so violent? Violent eruptions normally eject a large quantity of hot volcanic ash, explosively propelled by rapidly moving hot gas. By volume most of the hot gas is water vapor (steam).

Some of the mechanisms of violent gas-driven eruptions can be demonstrated in an easily performed experiment known as the "beer-bottle model." Volcano specialists report that this experiment is best performed on a hot summer afternoon in West Texas. Place a bottle of your favorite carbonated beverage on a table, letting it warm to summer afternoon temperatures. Gently remove the cap and reaffirm the expected: many bubbles will form within the liquid, creating a "head." As the head expands to fill more volume than is available in the top of the bottle, froth overflows onto the table top. Now, grasping the bottle firmly, place a thumb firmly over the top of the bottle. Shake the bottle vigorously and abruptly remove the thumb from the top of the bottle. If the experiment has been performed properly, the contents of the beverage container will tend to erupt vigorously, dispersing ejecta over a fairly large area.

Volcano eruptions are similar. In the experimental model of a gas-driven eruption described above, gas (carbon dioxide) was dissolved in a liquid. Liquids can contain dissolved solids (for example, sugar dissolved in coffee), other liquids (alcohol dissolved in gasoline), and gases (air dissolved in water). Increased pressure will cause greater quantities of gas to be dissolved in any liquid. If a liquid under high pressure holds as much dissolved gas as it possibly can (it is then saturated with that gas) and the pressure is then reduced, the liquid can then no longer hold as much of the gas. The excess dissolved gas is forced out of solution and oftens forms bubbles within the liquid.

In the experiment with a carbonated beverage, the gas involved is carbon dioxide. During the bottling gas was introduced under pressure and the beverage dissolved as much carbon dioxide as it possibly could; the beverage became saturated, under pressure, with the gas. When the bottle cap is removed, the pressure on the liquid suddenly drops to atmospheric pressure. The liquid can no longer hold as much carbon dioxide in solution and bubbles immediately form, rising to the surface and creating the "head." Violent agitation and abrupt reduction of pressure cause the bubbles to form much more abruptly and explosively; the beverage, propelled by the gas, erupts from the bottle.

How does this apply to volcanoes? Molten rock (magma) is a liquid that almost always contains some dissolved water. The magma chambers that feed erupting volcanoes are usually a mile or more beneath the surface. The column of molten rock within the volcanic neck weighs a tremendous amount; pressures within the magma chamber are many times higher than surface pressure. As any given volume of magma rises from the magma chamber upward through the liquid-filled volcanic vent, the weight of the overlying column of magma (and, therefore, the confining pressure) is continuously reduced. If there is very little water dissolved in the magma, the magma that reaches the surface still contains that dissolved water and will normally flow slowly as a tongue of lava down the flanks of the volcano. If, however, the magma contains more water, as it rises vertically upward through the vent and the confining pressure is continuously reduced, some point may be reached where the magma can no longer continue to hold all that water that is dissolved within it. At this point the excess water is forced out of solution in a manner similar to the way excess carbon dioxide was forced out of solution by lowered pressures in the experiment with the carbonated beverage.

Magmas, however, are very hot, usually in the range of 700°-1200°C. Therefore, when water is forced out of solution in a volcanic vent, the high temperatures immediately cause it to "flash" into steam. Steam occupies a tremendously greater volume than an equal amount of water. Therefore, when a small amount of dissolved water within the molten magma (taking up only a small volume while dissolved) suddenly becomes a very large volume of live steam, the suddenly-formed head erupts violently. A magma which may contain only a few percent dissolved water in the magma chamber a mile beneath the surface may eject, through the volcanic orifice, material that may be more than 90% live steam and other gases, containing only a few percent solid or molten material.

Violent volcanic eruptions are, therefore, driven mostly by self-generated live steam. The magma is atomized and blown out as tiny fragments, some of which rise thousands of meters into the air. The small droplets of magma condense to form tiny particles of volcanic glass (volcanic ash), which can remain suspended in the atmosphere for many days and drift great distances. Much ash falls to earth fairly close to the vent, creating blankets of ash that are later cemented to form rocks called volcanic tuffs.

In addition, the steam erupted from a volcano cools and condenses as water around tiny dust and ash particles in the atmosphere. It is not uncommon to have violent rainfalls associated with steam-driven volcanic eruptions, and it is not surprising that a large volume of stream-deposited sedimentary material (containing much volcanic ash as well as larger pebbles, boulders, and cobbles) is normally associated with volcanic ash deposits.

In rare instances exceptionally violent eruptions of extremely hot ash occur. Such events can result in the deposit of unusual, but extremely interesting, rocks called welded tuffs. Two things must happen to allow welded tuffs to form.

First, the extreme temperatures and violent eruptions mix large quantities of superheated air with the erupting atomized magma. In addition, the newly-formed, hot volcanic ash particles continue to give off gases (largely water vapor) as they cool. This results in the phenomenon known as an air-suspended turbidity flow. In this sense, "turbid" refers to "dirty," and the result is a volume of dirty gas (hot air and volcanic gases containing suspended, hot ash particles) rapidly flowing downhill through a volume of surrounding clean, cool air. This phenomenon is very much like the rapid flow of an avalanche of powdered snow and is analogous to muddy water flowing downward through clear water along the inclined floor of a lake.

Air-suspended turbidity flows of hot volcanic ash can move along slopes with relatively gentle gradients (only a few degrees) at speeds in excess of 200 km per hour (more than 100 miles per hour). When the superheated air and volcanic gasses escape from the rapidly moving mass of hot gas and ash, the ash comes to a very sudden and abrupt stop. (Again, the analogy is with an air-suspended powder-snow avalanche which suddenly comes to a halt as the air-suspension is lost, possibly encasing a trapped skier in a concrete-like mass of cold snow.)

The second thing that must happen to form a welded tuff is that the ash must be so very hot when the flow comes to rest that the ash shards melt and fuse together, forming a very dense, hard, volcanic rock; hence, the name "welded tuff."

Welded tuff deposits are extremely important geologically. They are hard and resistant rocks that usually form characteristic outcrops with a distinctive appearance in the field. In addition, the special cooling history that is shared by most welded tuffs causes relatively unusual minerals to form. The most obvious of these characteristic minerals is a special type of potassic feldspar called moonstone. Some crystal faces of moonstone will exhibit a characteristic bright iridescent blue appearance in reflected sunlight.

Furthermore, welded tuffs tend to be much more widespread than other volcanic deposits. This is especially useful in understanding local geologic history in situations where a number of volcanic centers occur, as is the case in the Big Bend area of Trans-Pecos Texas. The individual volcanic centers have deposited rock formations, most of which extend several kilometers (a few may extend tens of kilometers) from their own eruptive centers. Many of the formations do not interfinger with deposits from another vent. A welded tuff deposit is an exception, as it may extend for hundreds of kilometers and lap on to deposits from many individual eruptive centers.

In striking contrast to most sedimentary rocks, which may have taken thousands to millions of years to be deposited, welded tuffs are about the closest thing in the geologic record to "instant rock." They may literally represent an event that occurred in a few hours or a series of very closely spaced, brief events that occurred over a period of a few days or weeks.

Because welded tuffs tend to cover such large areas when compared to the other volcanic deposits and because they represent what is relatively an instant of geologic time, they are extremely important to the geologist who is attempting to correlate the sequence of events from one eruptive center to another. Two welded tuffs occur in the Bofecillos Mountains area: the Mitchell Mesa Tuff and the Santana Tuff. They are the keys to understanding many of the relationships between the lava flows and ash falls that issued from the Bofecillos Vent and similar deposits associated with surrounding volcanic activity.

The volcanic events of southeastern Presidio County can be summarized more easily with this introduction in mind. As indicated earlier, Laramide mountain building led into a sequence of Tertiary volcanic events that affected most of the southern and western United States and northern Mexico. In the Big Bend area of Trans-Pecos Texas these events were mostly of Eocene and Oligocene age (20-60 million years ago).

The details of the volcanic stratigraphy in West Texas are extremely complicated; there are many individual beds that were erupted from a number of distinctly isolated volcanic centers. There were several major eruptive centers and many minor ones in the Big Bend area. Major centers include the Chisos Mountains in Big Bend National Park, Davis Mountains, Chinati Peak, and several south of the Rio Grande in Mexico. The Bofecillos Volcano was a relatively small and localized eruptive center active toward the close of the main series of volcanic events. The eruptive centers discharged both molten magma (feeding lava flows) and violent to extremely violent eruptions ejecting large quantities of volcanic ash. Three strikingly different types of igneous rocks were formed: solidified lava flows, tuffs (soft volcanic ash deposits), and welded tuffs. Because the volcanoes were erupting on a landscape surface, sedimentary rocks deposited by running water, wind, and slope processes are often associated and interbedded with the volcanic rock. As the intensity of volcanic activity decreased at any one of the vent areas, molten magma commonly was squeezed into the previously deposited lava flows, ash falls, and sedimentary deposits. The intrusions usually lacked sufficient energy to breach the surface and tended to uplift and dome the overlying and slightly older layered rocks.

If we look at any given volcanic vent area (the Bofecillos Volcano is a beautiful example), we find that close to the vent area lava flows dominate the stratigraphic section. More distant in all directions from the vent itself, progressively more ash and less lava are present.

The following description of the Tertiary volcanic rocks and associated stream-deposited sediments is a summary of the information presented in more detail in Appendix 1.

Jeff Conglomerate

Overlying the older Cretaceous sedimentary rocks, and nearly everywhere underlying the base of the volcanic sequence, is a coarse-grained sedimentary conglomerate called the Jeff Conglomerate, containing boulders up to 35 cm in diameter. The Jeff Conglomerate is exposed around the edges of the Bofecillos Mountains and near the center of the Bofecillos Volcano in Rancherias Dome (McKnight 1968:25). It is described in more detail by McKnight (1968) and in the companion volume on Fresno Canyon (Deal 1976a).

Chisos Formation

The lowermost volcanic rocks that overlie the Jeff Conglomerate in the Bofecillos Mountains are a sequence of soft, light-colored, easily eroded beds of the Chisos Formation. They are formed largely from volcanic ash falls and contain associated stream deposits (conglomerate and sandstone), mud flows, lake deposits (non-marine limestone), and windblown ash, dust, and sand. Most of the Chisos Formation was probably erupted from vents southeast of the Bofecillos Mountains, in the vicinity of what is now Big Bend National Park. Since the Bofecillos Mountains area is some distance from the eruptive centers, the Chisos Formation, as expected, is composed dominantly of ash falls and associated sedimentary deposits. Few of the lava flows were extensive enough to reach the Bofecillos Mountains. The age of the Chisos Formation is discussed in more detail in Appendix 1, but potassium-argon radiometric age determinations indicate that it may have been deposited between 20 million and 45 million years ago (Maxwell and others 1967:137).

A 1-m thick bed of ash-flow tuff within the Chisos Formation and above the Mule Ear Spring Tuff is exposed along Tapado Creek at the southwest end of Tapado Dome (see Appendix 1). This unit contains a layer of black perlitic obsidian up to 30 cm thick that was locally used by prehistoric inhabitants of the area to make stone tools.

Mitchell Mesa Tuff

Overlying the Chisos beds is the Mitchell Mesa Tuff, one of the widespread, distinctive, welded tuffs mentioned previously. In most places it forms a very resistant layer that the non-geologist would probably mistake for a solidified lava flow. It is not, however, an ancient lava flow but originated from what was probably either a single, violent eruption or a series of closely related violent eruptions of large quantities of very hot volcanic ash. The particles of ash were so hot when they came to rest that most places they fused together and "welded" themselves into this very hard and resistant unit. A deposit of this type is referred to as an "ignimbrite" or welded tuff (see introductory discussion of volcanic processes).

The top of the Mitchell Mesa Tuff is one of the most useful horizons for the stratigraphic correlation of the volcanic rocks in the Big Bend region of Texas. Not only does it form a hard, resistant, distinctive unit, it covers an immense area. Known occurrences extend from the area of Big Bend Park northward to the Davis Mountains (north of Alpine) and westward (where it is called the Brite Ignimbrite) to the rim rock country south of Van Horn. Dietrich (1965) estimated a minimum aerial extent of 4 million hectares (2500 square miles) in the United States and Haenggi (1966) estimates a minimum of an additional one million hectares (700 square miles) in Mexico, west of Presidio.

Additional information is included in Appendix 1.

The Bofecillos Volcano and Associated Deposits

Within the Bofecillos Mountains, the Mitchell Mesa is a cliff-forming ash-flow tuff and is mostly between 6 and 11 m (20 and 35 ft) thick. Its maximum thickness is about 15 m (50 ft) (McKnight 1968:57). It thins against the flank of the Solitario. In Fresno Canyon, south of the Smith house, it pinches out and is often not thoroughly welded. (For more detailed discussion of this area, see the companion volume on Fresno Canyon, Deal 1976a.)

Both the Chisos Formation and the Mitchell Mesa Tuff were erupted from centers outside the Bofecillos Mountains area. About the time that the Mitchell Mesa event occurred, the initial stages of the eruption of the Bofecillos Volcano began. Initial eruptions were of ash and lava, which interfingered with some tuff deposits that probably originated from other eruptive centers. As volcanic activity at the Bofecillos Vent increased, a progressively more complex sequence of lava flows, ash falls, and associated sedimentary material accumulated. The sequence was further complicated by local intrusions that did not reach the surface, but domed and uplifted the previously deposited rocks. Block faulting also complicated the structure on the flanks of the volcano. These units are described in more detail in Appendix 1.

Approximately halfway through the growth of the Bofecillos Volcano, another welded tuff unit, the Santana Tuff, probably erupted from a vent in Mexico southeast of the Bofecillos Mountains, lapped onto the flank of the Bofecillos Volcano. This unit is not as widespread as the Mitchell Mesa Tuff but is still extremely useful in the correlation of other less widespread volcanic strata in the area. The Santana Tuff is a distinctive unit in the field and conveniently separates the igneous and sedimentary rocks of the Bofecillos Volcano into upper and lower units.

By definition then, all rocks between the top of the Mitchell Mesa Tuff and below the Santana Tuff are called the Fresno Formation. All of the volcanic rocks that lie above the Santana Tuff are defined as the Rawls Formation. The Fresno Formation is composed mostly of lava flows and ash falls that erupted during the early stages of the growth of the Bofecillos Volcano. The Rawls Formation is composed mostly of lava flows and ash falls erupted during the late stages of the Bofecillos Volcano, but includes some units that may have come from other vent areas. Dietrich (1965) located a probable major vent for some of the rocks in Rawls Member Number 8 ($Tr8_a$) northwest of the Bofecillos Mountains.

Figure 11 diagramatically summarizes the growth of the Bofecillos Volcano.

TERTIARY INTRUSIVE EVENTS

Both during and following the main eruptive stages of the Bofecillos Volcano, magma was forced into the previously deposited rock units. In many instances the magma did not break through to the surface and created domal uplifts. Some of the intrusions, however, did feed vents that erupted lava and ash. The intrusions took many forms and are described in more detail in Appendix 2. Tabular intrusions that cut more or less vertically through the surrounding rocks are called dikes and are abundant in and around the Bofecillos Volcano. Dikes become progressively less common away from the main vent area; McKnight shows only the largest ones on his geologic map. In some instances, slight movement as the magma was almost completely solidified caused highly polished and grooved surfaces ("slickensides") to form. These can be observed at many places in the Bofecillos Mountains. The most scenic and spectacular exposure I noticed was on the western side of Tapado Canyon, a few hundred yards upstream (north) of Tapado Springs (Fig. 12). Tabular intrusive bodies that are parallel to the bedding of existing rocks are called sills. Sills are much less numerous than dikes in the study area.

The composition of dikes and sills present in the study area is similar to that of the lava flows in the Fresno and Rawls Formations. The dikes and sills are, however, more intensely altered than the flows. By far the most abundant dike rock is a latite porphyry which forms dikes as much as 6 m thick and several kilometers long. The intrusion of hot magma caused some contact alteration effects in the surrounding rocks which extend at most a few meters on either side of the dike or sill. Iron-oxide staining normally is the only noticeable evidence of the alteration of the intruded flow rocks, but tuff is commonly baked and oxidized to a red-brown, creating a slightly harder rock, more resistant to erosion than the unaltered tuff farther from the intrusion (McKnight 1968:104).

Intrusions that have a generally upside-down saucer-like shape (a generally horizontal base and a domed top) are called laccoliths. In the study area, most of the laccoliths are found where magma has intruded into the thin-bedded Boquillas Formation of Cretaceous age that lies beneath the Tertiary volcanic sequence. A few laccoliths are emplaced beneath some of the thicker lava flows present in the Bofecillos Mountains. Most of the well-exposed laccoliths are to the southwest of the Bofecillos Mountains and are described in more detail in the companion volume on Fresno Canyon (Deal 1976a). The numerous domal uplifts in the map area (see both the earlier discussion and the geologic map by McKnight 1970) are probably caused by intrusions at depth. Some of these domal areas are described in more detail in Appendix 2.

THE BOFECILLOS VENTS

The Bofecillos Volcano erupted from two vents partially surrounded by intrusions and a breccia zone. They are located approximately 6 km (3.5 miles) west and slightly south of Sauceda Ranch (Big Bend Ranch Headquarters), about 3 km (2 miles) southeast of the Agua Adentro Shearing Pens. The east vent is about 2 km (1.1 miles) and the west vent about 1 km

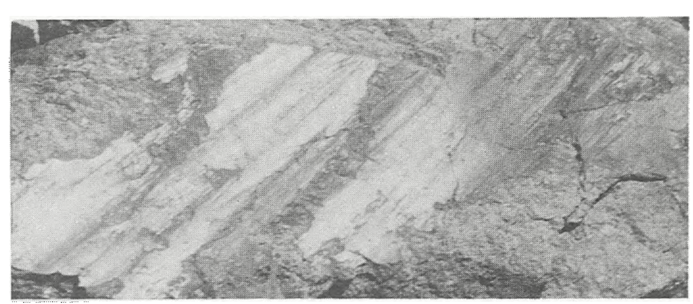


FIGURE 12

Slickensides on a dike rock in Tapado Canyon. Photo by Dwight Deal

(0.6 miles) in diameter. Most of the vent material is a poorly consolidated breccia consisting of clay-, silt-, and sand-size fragments containing occasional angular blocks which range up to 3 m (10 ft) across. The vent area is also described in more detail in Appendix 2.

TERTIARY AND QUATERNARY FAULTING

Thrust faults that are interpreted as gravity slides are exposed at four locations in the eastern part of the Bofecillos volcanic field. A gravity-slide thrust fault is one that formed when a large block of rock slid down the side of an uplift or other topographic high. Most of the gravity-slide thrust faults are located in Fresno Canyon and are discussed in more detail in the companion volume on Fresno Canyon (Deal 1976a). McKnight (1968:119-120) described the intensely deformed and faulted rocks on the eastern side of Llano Dome, an uplift approximately 4 km (2.5 miles) southeast of Sauceda Ranch Headquarters. The intensity of the thrusting and folding, which involves Tertiary volcanic rocks of the Chisos, Mitchell Mesa, and Fresno Formations, is unusual for the Bofecillos Mountains area. Some of the slabs have apparently been rotated more than 130° through the vertical axis so that rocks that were initially nearly horizontal are now overturned, upside down, and dipping at 50°. McKnight's (1968:119-120) attempt to explain these structures is included in Appendix 2.

A number of normal faults, some with as much as 600 m (2000 ft) of throw, cut the central and southern parts of the Bofecillos Mountains (Fig. 7). These faults, which follow regional trends, were probably active throughout the period of Tertiary volcanism. Continued displacements along these faults have occurred since the cessation of activity on the Bofecillos Volcano and have probably been active into the Quaternary. McKnight (1968:121-126) describes the normal faulting as follows:

> **Fault zones.** – Normal faults trend generally northwestward; they are sloped in the Redford-Lajitas (Dietrich 1965:174-175) and Bofecillos fault zones. Faulting of the 5- to 15-mile-wide Redford-Lajitas fault zone is typical of that elsewhere in the Basin and Range Province; the faults form a compound, step-faulted graben centered along the southwest boundary of the map area. Structural relief of the graben ranges from 1,000 to 2,500 feet; it may be distributed more or less evenly over a broad belt of a dozen or more faults and tilted fault blocks, or may be concentrated on a single fault with 2,000 feet or more of throw. The southwest side of some faults on the United States side of the graben is upthrown, producing horst blocks that interrupt the over-all down-to-the-southwest step-fault pattern (Fig. 7); such horsts are relatively more common

EXPLANATION OF FIGURE 11

	Rawls Formation
8a	member 8, trachyandesite
8bp	member 8, trachybasalt porphyry
7at	member 7, ash-flow tuff
5a	member 5, trachyandesite
4bp	member 4, trachybasalt porphyry
2t	member 2, tuff
1b	member 1, basalt
	Santana Tuff
S	ash-flow tuff
	Fresno Formation
F	undifferentiated
1p	latite porphyry
a	trachyandesite
	Mitchell Mesa Tuff
MM	ash-flow tuff
	Chisos Formation
C	undifferentiated
t	Tule Mountain Trachyandesite porphyry
mes	Mule Ear Spring Tuff
bm	Bee Mountain Basalt
ac	Alamo Creek Basalt
	Jeff Conglomerate
J	conglomerate
	Cretaceous strata
K	undifferentiated
bo	Boquillas Formation
bu	Buda Limestone
dr	Del Rio Formation
se	Santa Elena Limestone
	Intrusive rock
i	undifferentiated

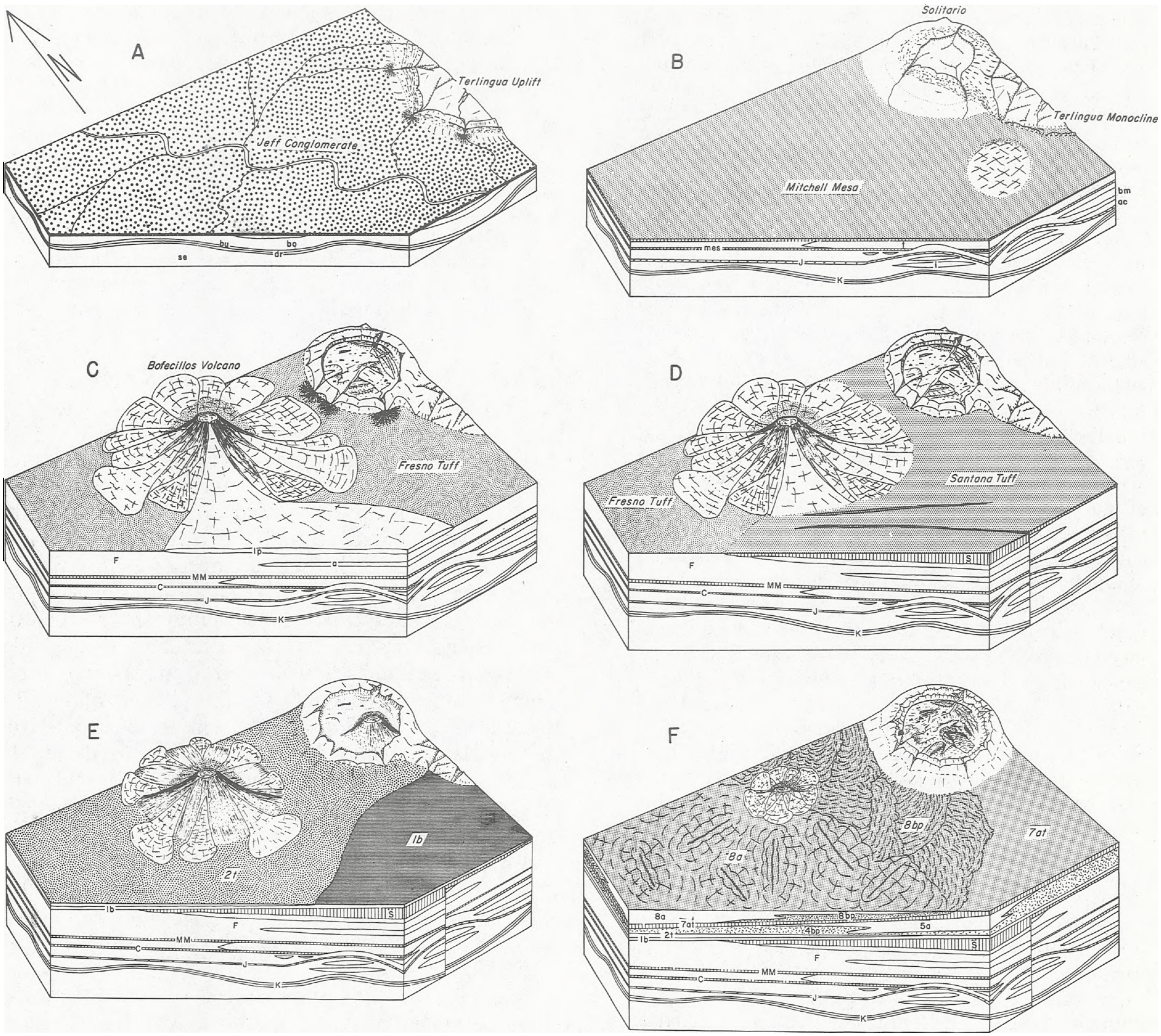


FIGURE 11

Summary of major events in the development of the Bofecillos Mountains Area.
(From McKnight 1968: Fig. 21)

along the northeast edge of the graben complex than near the axis. The intersecting, complexly arcuate faults are as much as 12 miles long. Most are high-angle normal faults, but a few dip 45° or less where they cut structurally anisotropic lava flows such as the Tule Mountain Trachyandesite Porphyry and latite lava flows of the Bofecillos Volcano. At no place was it possible to demonstrate reverse faulting. The Redford-Lajitas fault zone curves from a trend of about N 50° W at the west end of the map area to about N 70° W at the east end; the change is most pronounced at Tapado Canyon where the faults bend southwestward around the approximate outline of the Bofecillos Volcano, perhaps because intrusions at depth in or under the Bofecillos Volcano created a massif that deflected the fault zone.

The one- to three-mile-wide Bofecillos fault zone cuts across the center of the map area to about N 50° W through the vent area of the Bofecillos Volcano; it extends about 5 miles both to the southeast and northwest of the two vents. In contrast to the faults of the Redford-Lajitas zone, those of the Bofecillos zone are straight high-angle faults, mostly less than 2 miles long, and mostly with less than 100 feet of throw; they produce jostled fault blocks but no step-faulted graben structures. These differences suggest genetic and perhaps temporal differences in the formation of the two zones. Perhaps faults of the Bofecillos zone are upward extensions of an early-formed fissure system that fed the volcano. Alternatively, the faults may be in a modified radial pattern caused by uplift of the volcanic center, as suggested by a few faults east and south of the vent area with radial trends; scarcity of faults at trends other than northwest might be caused by a northeast-southwest-regional stress acting at the time of eruption. Finally, a few faults within the zone might be caused by local stresses: the rather random fault pattern immediately northwest of the west vent may be caused by a small intrusive dome and an arcuate fault on the north side of the two vents may be a collapse structure caused by cauldron subsidence.

Time of faulting. – Normal faults following regional trends were probably active throughout the period of Tertiary volcanism, but faulting that occurred before deposition of the upper part of the Rawls Formation is difficult to document because later movement along early-formed faults has obscured evidence of the early movement. In the Bofecillos fault zone, exposures are poor, but, in the Redford-Lajitas fault zone, there is ample indirect evidence, in the form of abrupt thickening of stratigraphic sequences, to indicate early faulting. For example, in Carrasco Dome north of Texas Route 170, at least one fault occurred between the spreading of the Mule Ear Spring and Mitchell Mesa ashflows, because the stratigraphic interval between them ranges from less than a foot on a knob to the southeast to more than 50 feet across arroyos to the north and west. Similarly, about a mile northeast of Santana Mesa faulting occurred before emplacement of the Santana, because its thickness across a fault ranges from 30 feet on the upthrown side to more than 100 feet on the downthrown side; renewed movement on the fault separated the top of the Santana several hundred feet, and the abrupt change in thickness is only demonstrable in Madera and Panther Canyons.

Field relationships, however, indicate that most of the block faulting occurred after the deposition of volcanic strata: 1) faults cut the youngest volcanic strata and the bolson fill; 2) faults are not perceptibly more abundant in older strata–fewer faults were mapped in the late- and post-volcanic bolson fill principally because exposures are poor, rather than because of an actual decrease in fault abundance; 3) at no place in the area was a fault found truncated by strata older than Quaternary gravel; 4) significant differences in thickness of given intervals of volcanic strata across faults–indicating early faulting–are relatively uncommon. Dietrich (1965:216) reported faults displacing Quaternary pediment gravel in the Presidio area, a fact suggesting that faulting continued throughout the later part of the Cenozoic era.

TERTIARY AND QUATERNARY SEDIMENTARY DEPOSITS

Sedimentary fill in the basins along the Rio Grande accumulated during late Tertiary and Quaternary time. After an initial period of basin filling, the bolsons were breached and the through-flowing Rio Grande or Rio Conchos drainage was established through the Big Bend area. Later deposits are intimately associated with the development of the Rio Grande and the Rio Conchos drainages through the Big Bend area and are discussed in more detail in the companion volume on Colorado Canyon of the Rio Grande (Deal 1976c). In addition to locally derived subangular volcanic rock fragments, the basin deposits contain pink conglomeritic sandstones with angular to rounded fragments of volcanic and sedimentary rock. The fragments in these conglomeritic sandstones were probably transported considerable distances. At least 45 m of bolson fill is exposed in the Redford bolson; and in the Santana bolson, bolson fill sediments are exposed in the road cut at the top of the Big Hill.

The Rio Grande experienced alternate times of rapid downcutting and stability. The tributaries to the Rio Grande that were dissecting the Bofecillos Volcano reflected those alternations. During periods of relative stability, both the main stream and the side streams eroded surfaces of lateral planation (chiefly cut on the valley-fill sediments). During periods of more rapid downcutting, the streams incised the previously formed planation surfaces. The resultant steplike sequence of gravel-mantled pediments and terraces is strikingly exhibited in the Bofecillos Mountains area. McKnight (1968:113-115) describes the pediment and terrace gravels as follows:

> The most extensive pediment and terrace deposits are in the Redford Bolson where four gravel sheets are numbered in order, in accordance with the system started by Amsbury (1959) and modified by Dietrich (1965:168); the highest (oldest) is Qg1 and the lowest Qg4. Only a few remnants are preserved of the pediment gravel Qg1; mostly they are close to and sloping steeply from the high-standing parts of the Bofecillos Mountains. The gravel projects everywhere to about the same height above the Rio Grande, but the remnants are so widely separated and far-removed from the river that the correlation expressed by the symbol Qg1 is very loose and does not imply a single period of base level stability. Gravels Qg2 and Qg3 are remnants of extensive sheets mapped by Dietrich (1965) in the Presidio Bolson and in the northwest part of the Redford Bolson. Gravel Qg4 includes all pediment and terrace deposits between gravel Qg3 and flood plain alluvium of the Rio Grande and its tributaries.
>
> Two extensive gravel sheets in the Santana Bolson are tentatively correlated with Qg1 and Qg2 of the Redford Bolson, which they resemble in projected height above the Rio Grande, degree of cementation and dissection, and tone on aerial photographs. On the same basis, three gravel sheets that extend across Contrabando Lowland and into Fresno Canyon are tentatively correlated with Qg2, Wg3, and Qg4 of the Redford Bolson. Elsewhere in the map area, pediment and terrace gravels are undifferentiated Qg.

In addition to these older deposits, modern stream and slope deposits are found in the area.

McKnight (1968:115) describes two types of modern Rio Grande stream river deposits. The channel gravel is made up of rounded pebbles, cobbles, and boulders, mostly of volcanic rocks and as much as 1 m (3 ft) in diameter, in a matrix of sand and silt. As expected, the channel gravel strongly resembles the slightly older Rio Grande terrace gravels. The flood plain deposits, however, are much finer grained, consisting dominately of clay-rich silty sand.

Most of the side-stream channels are dry except during storms when flash flooding commonly occurs. The sediments in the side-stream channels are often sandy gravel to very gravelly sand and contain a wide variety of rock types that represent the geology of each individual drainage basin. In the mountains, slump or landslide blocks occasionally block the channel. These materials move downstream only during flash floods.

Slope deposits (colluvium) are the most common sedimentary material in most of the Bofecillos Mountains area and ranges from a thin veneer of soil to large piles of bare talus. McKnight (1970) mapped slope deposits only where the talus cover was "so thick that an attempt to infer the underlying geology is not warranted."

MINERAL RESOURCES

Mercury

The Terlingua Quicksilver District adjoins the southeastern edge of the Bofecillos Mountains. A more complete discussion of the mercury resources for that area is contained in the companion volume on Fresno Canyon (Deal 1976a). McKnight (1968:135-139) discusses in some detail the possibilities for additional mercury ore development in the Bofecillos Mountains area. Mineralization has proven to be economically significant only where it has occurred in the uppermost sediments of Cretaceous age. In most of the Bofecillos Mountains, these rocks are covered by more than 300 m of Tertiary volcanic strata. Even should ores occur in the Cretaceous rocks, exploitation would seem unlikely to be economic in the near future. McKnight (1968:137), in describing the mercury potential for the Bofecillos Mountains area, concludes that a prospector:

> should examine the possibilities of finding mercury deposits in northeast-trending fractures in the volcanic and intrusive rocks; from what is known in the Terlingua District, however, such occurrences of mineralization would have relatively little chance of being minable ore bodies. Attention might better be focused on intrusive domes where Cretaceous strata are nearer the surface. Rancherias Dome is probably the most favorable of the known domes because there are Cretaceous strata at the surface, numerous siliceous fissure veins, and abundant iron oxide stains.

Bentonitic Clay

Some of the volcanic ash in the Bofecillos Mountains, particularly ash occurring in the lower parts of the ash flows, contains bentonitic clay that might be of economic value if (1) it meets industry's specifications, and (2) it is present in sufficient volume. Dietrich (1965) reports prospect pits in the Fresno Formation on the western flank of the Bofecillos Mountains, northwest of Carrasco Dome (about 8 km northwest of Redford), but they are of little economic interest. McKnight (1968:139) discusses the prospects for bentonitic clay within the Bofecillos Mountains as follows:

> At the south end of Tapado Dome, a 3- to 6-foot bentonitic zone of unknown lateral extent at the base of the Mule Ear Spring Tuff is remote from good roads and has a thick overburden laced with lava flows. It would not be amenable to stripping without drilling and blasting. Bentonitic clay probably exists partly or totally covered elsewhere in the map area. The base of the Santana Tuff is probably the most likely stratigraphic interval for an economic deposit because it is part of a thick unit and therefore has at least the potential of containing a thick deposit; furthermore this part of the Santana is mostly covered by talus from the steep slopes above—possible deposits near the base are therefore covered.

Perlite

Some of the volcanic glass rocks contain enough water so that when they are heated they expand markedly. Many of the volcanic glasses that do contain large quantities of water have characteristic small, concentric fracture patterns about the size and shape of pearls; hence, the common name "perlite." The name perlite has been extended in industrial use to apply to all volcanic glasses that adequately expand when heated, whether or not they exhibit the characteristic concentric fracture patterns. Expanded perlite has been used for a variety of purposes, including insulation and lightweight aggregates. The increased need for lightweight aggregates in construction has created most of the modern demand for perlite, and some is now being mined about 50 km northwest of Presidio in Pinto Canyon. McKnight (1968:140) describes one known perlite deposit in the Bofecillos Mountains as follows:

> The only perlite found in the Bofecillos Mountains Area is a poorly exposed, foot-thick stringer about 50 feet in outcrop length that occurs in Rawls Tr_{2t} tuff on the south side of the Bofecillos Volcano. This exposure is immediately west of the jeep track that extends about one-half mile south of the junction of the jeep track with the road between the Bofecillos vents and Rancherias Dome. The rock contains less than 1 percent of feldspar phenocrysts and basaltic hornblende; the groundmass is green perlitic glass, about one-third of which is altered or weathered to yellow-green zeolites. Its origin is uncertain; it may have been tuff fused by an unexposed dike or sill, or the tuff may have been hot enough to weld after it settled. Because of the uncertainty of origin, it is impossible to assess the likelihood of more extensive deposits occurring elsewhere in the area. This stringer is not nearly big enough for a deposit to be economically exploitable, and it was not tested for expansion characteristics.

Water Resources

Most of the water currently flowing through the Rio Grande in Big Bend Park is supplied by the Rio Conchos, heading in Mexico, not the Rio Grande, heading north of El Paso (see charts in the companion volume on Colorado Canyon, Deal 1976c). The Rio Grande upstream from Presidio rarely carries much flowing water except after intense summer cloudbursts. The extensive removal of water for irrigation in New Mexico and in the vicinity of El Paso is unquestionably quite significant; however, accounts of early travelers in the area indicate that low stream flow has long been a recurring condition along this segment of the Rio Grande and that current upstream use has only accentuated the problem, causing the recurrent droughts of the past to become nearly permanent (Deal 1973:61-64; 1976c:Table 2).

The Rio Conchos currently has ample enough flow where it empties into the Rio Grande at Presidio to provide for irrigation of farms on the Rio Grande flood plain in the Presidio and Redford areas. Additional cultivation upstream in Mexico will probably require the most efficient use possible by all concerned and will probably result in some international as well as local problems in the not-too-far-distant future.

Ground water is readily available at depths of 10 m or less from gravel lenses in the deposits of the Rio Grande valley floodplain. The quality of this water is not good. It usually contains dissolved salts in concentrations sufficiently high to make the water unpalatable to nonresidents of the area. Analysis of water from well UW-74-39-501 near Redford by the U.S. Salinity Laboratory of the United States Department of Agriculture (as reported by Davis and Leggat 1965: Table U 3) is reproduced in Table 3. Fresher water, resulting from the infiltration of local rains, locally occurs on the edges of the Rio Grande valley floodplain and occasionally beneath the more saline Rio Grande waters (McKnight 1968:140-142).

Springs and Seeps

A large number of seeps and springs, mostly with rather small flow, are common through the Bofecillos Mountains. There are two basic types: (1) those that result from ground water discharging from bedrock aquifers in the underlying volcanic and sedimentary rocks ("primary springs"), and (2) those that occur in the bottom of arroyos where resistant and impermeable strata force water that is moving through the unconsolidated sand and gravel to the surface. Most of the springs and seeps of the second type occur in the arroyo bottoms below springs of the first type and, depending upon the season, running surface water may occur below them for distances from a few meters to several kilometers, usually sinking back into the unconsolidated stream sediments before reaching the Rio Grande.

Volcanic rocks in the lower part of the Rawls Formation and the upper part of the Fresno Formation are the most important aquifers in the area. These aquifers are normally porous zones at the top or bottom of individual lava flows or, in some cases, lenses of stream-deposited conglomerate, gravel, or sand within the sequence of ash deposits. In most instances the volcanic ash deposits themselves are too fine-grained and impermeable to be effective aquifers.

Most of the type 1 springs in the eastern part of the Bofecillos Mountains flow from porous zones at the top and bottom of individual basaltic flows, most of which fall within the unit mapped by McKnight (1970) as part of his $Tr4_{bp}$ member of the Rawls

TABLE 3

Composition of well water from 3 wells and a spring in the Bofecillos Mountains and vicinity
Modified by McKnight (1968:141) from Davis and Leggat (1965: Table U 3)

	A	B	C	D
Well number	UN-74-39-501	UW-74-32-401		
Water-bearing Unit	Rio Grande Alluvium	Tertiary igneous rock	Tertiary igneous rock	
Depth of well (feet)	25	spring	?	
Date of collection	11/2/49	11/23/49		
Analysis (in ppm unless stated otherwise):				
Silica (SiO_2)	67	59		
Iron (Fe)				0.3
Manganese (Mn)				0.05
Calcium (Ca)	125	44		
Magnesium (Mg)	21	6		
Sodium (Na)	439	24		
Potassium (K)	5.1	2.0		
Bicarbonate (HCO_3)	252	151		
Sulfate (SO_4)	566	20	46	250
Chloride (Cl)	383	16	22	250
Fluoride (F)	4.0	1.1		1.7 max.
Nitrate (NO_3)	32	12		45
Boron (B)	0.5	0.13		
Dissolved solids	1,790	257	405	500
Hardness as $CaCO_3$	398	134		
Percent sodium (Na)	70	28		
Sodium Adsorption ratio (SAR)	9.6	0.9		
Specific conductance (micromhos at 25°C)	2,650	359		
pH	7.6	7.8		

Analyses A, B, and C by U.S. Salinity Laboratory of U.S. Department of Agriculture:

A. Well in Rio Grande alluvium at Redford, Texas, analyzed by U.S. Salinity Laboratory of U.S. Dept. of Agriculture.

B. Flowing spring in Tertiary igneous strata (Tr8 or Tr9) in Presidio Area (Dietrich 1965), north of Torneras Creek, about 5 miles north of Bofecillos Mountains Area from Cuevas Amarillas Spring analyzed by U.S. Salinity Laboratory of U.S. Dept. of Agriculture.

C. Well in Presidio Area about 2 miles north of Bofecillos Mountains Area from Cuevas Amarillas Spring (probably at Rancho Viejo windmill) analyzed by U.S. Salinity Laboratory of U.S. Dept. of Agriculture.

Formation. These include the springs that feed Arroyo Segundo: Chilicote Spring (labeled, probably erroneously, Smith House Springs on the Sauceda Ranch 7.5-minute U.S.G.S. Quadrangle map) and Ojo Mexicano. Waters from this unit feed Cuevas Amarillas Spring in Bofecillos Canyon and are probably important in indirectly supplying the springs in the headwaters of Auras, Las Burras, Panther, and Madera Canyons. The primary springs at the head of Chorro Canyon, which feed Madrid Falls, also issue from this unit. For an additional discussion of the water resources in Arroyo Segundo and Arroyo Primero (Mexicano Falls and Madrid Falls), see the companion volume on Fresno Canyon (Deal 1976a).

The two welded tuff units in the area (the Mitchell Mesa Tuff and the Santana Tuff) are almost everywhere dense and impermeable. Any water in the units immediately above them (for example, in the base of the Fresno Formation or the base of the Rawls Formation or in unconsolidated stream alluvium) will tend to be forced to the surface where the welded tuffs are exposed. This is especially true in beds of arroyos: Arroyo Primero, Madera Canyon, Panther Canyon (Panther Springs), Rancherias Canyon (near its mouth), and Tapado Canyon. Elsewhere in the study area individual massive and impermeable lava flows also force water to the surface. This is particularly true of the latite porphyry near the top of the

Fresno Formation (this is the unit which holds up Mexicano Falls in Arroyo Segundo and is mapped by McKnight as his Tf_{lp} unit which is exposed at Rancherias Springs). Fractures and fault zones that cut these aquifers explain most of the other spring occurrences within the Bofecillos Mountains.

As with any ground-water flow system, the ground-water system beneath the Bofecillos Mountains has an input (recharge area), distributing conduits or beds (porous and permeable water-transmitting zones called aquifers), and discharge points (springs and seeps). The water in the system flows from areas of high pressure to areas of low pressure, in this case from higher elevations to lower elevations. The eroded central region of the Bofecillos Mountains is the recharge area for the water which flows from the type 1 springs. Ground-water flow is, for the most part, radially outward away from the recharge area, with discharge occurring at lower elevations around the dissected edges of the ancient Bofecillos Volcano.

Natural springs and seeps occur only where there is a surplus of underground water, often at locations fairly far removed from the recharge areas. The drilling and development of water wells in much of Trans-Pecos Texas has removed water artificially from many aquifers, reducing the amount available at their extremities to support spring flow. In many instances this has resulted in a general lowering of the water table and the drying up of many springs. An unusual history of land use in the Bofecillos Mountains accounts for the fact that most of the springs in this area still flow copiously.

Most of the Bofecillos Mountain country was extensively developed by the Foulkes brothers in the 1930s, 1940s, and 1950s. They intensively ranched the area, herding sheep and goats. Although there were many scattered seeps and springs on the ranch, many of these were in canyon bottoms and relatively inaccessible. There was an obvious need to supply water to the grasslands on the high mesas. Much of the Bofecillos Mountains country is so rugged that it was prohibitively expensive to build the roads necessary to move drilling rigs onto many of these high mesas. Papalote Severo, a windmill still supplying water to an area in the headwaters of the Auras Canyon, was packed in on horse- and mule-back and installed over a hand-dug well.

In most cases it was easier to set up windmills to pump water up to the high mesas from existing dependable springs than to drill or dig wells at the remote sites. The Foulkes brothers began to do this and then, at the close of World War II, acquired a large quantity of surplus pipe. An incredible system of overland pipelines and pumping windmills was constructed to distribute water from natural springs and one or two good wells. Ralph Hager (oral communication, 1975), foreman of Big Bend Ranch, reports that at one time the Foulkes brothers had more than 1100 km (700 miles) of pipeline functional on Big Bend Ranch (enough to reach to Arkansas)!

The main water sources for the pipeline system within the Bofecillos Mountains were the springs near Sauceda headquarters and the good water well at Javelina Pump (about 8 km south of the headquarters, near the head of Panther and Madera Canyons). Not all of the 1100 km of pipeline are in the Bofecillos. Big Bend Ranch extends into surrounding areas and part of the elaborate system dispersed water in and around the Solitario. The Foulkes brothers sold their ranch during the drought of the late 1950s, and owners of Big Bend Ranch since that time have run relatively small numbers of stock, mostly cattle, on the land. Although much of the pipeline system has fallen into disuse, over 650 km (400 miles) is still functional, most of it distributing water to the high mesas in the southwestern part of the Bofecillos Mountains (Ralph Hager, oral communication, July 1975). A number of new water wells have been drilled in the Bofecillos in the past few years, but it is too early to determine what effect they will have on the springs. It is clearly a fact that the wells and the springs draw their water from the same bucket, and that bucket is refilled ultimately, from rain that falls in the recharge area. Continued development of water wells and withdrawal of underground water from the aquifers will eventually reduce spring flow. It was not within the scope of this study to determine the effect of the present artificial withdrawal on the springs, nor to predict the specific effects of further development.

With modern technology, it will probably become more economic to distribute water throughout the dry areas of the ranch from new, local wells rather than by overland pumping, as has been the case in the past. The unique and exceptional aesthetic values of the Bofecillos Mountains country is, however, largely a function of the presence of many springs. Managers of this area should realize that more water wells will ultimately mean less spring flow and fewer springs, and, if it is deemed desirable to preserve the natural ground water flow that occurs within the area, some extensive and careful studies should be made to determine as much as is possible about the specifics of the natural flow systems. Normal pump tests, which indicate the potential yield of a given water well, will not provide this kind of information. Ideally a network of rainfall and recharge monitoring stations, spring and stream gauges, and piezometer installations should be established throughout the area. Good piezometer data must be obtained from carefully selected sites. Depending upon the sophistication of the measurements and the number of measuring stations installed, enough information might be gathered in 5 or 10 years to allow cautious and carefully-monitored expanded development of the underground water resources to proceed with some knowledge as to which springs (if any) would likely be affected by the withdrawal of given quantities of water from any specific well.

If the decision is made to continue to develop additional dependable water wells in the area, likely target horizons would be porous zones within the Tr_{4bp} basalt flow unit, sandstone and conglomerate units at the base of the Rawls Formation immediately above the Santana Tuff, the upper portion of the Tf_{lp} latite porphyry lava flow in the upper part of the Fresno Formation and in the sandstone and conglomerate lenses immediately above it, and sandstone and conglomerate lenses near the base of the Fresno Formation immediately above the Mitchell Mesa Tuff. Shallow wells in the alluvium along the arroyos will only more efficiently remove what water is available within the stream sediments. Such wells will assuredly reduce or dry up the flow from the type 2 springs that occur immediately downstream from them. Specific well-site locations should be chosen with a general understanding of the flow within the natural ground-water system and should take advantage of local structure, fracture systems, and faults.

Petroleum and Natural Gas

The Bofecillos Mountains have not been drilled for oil or gas. The intensity of the intrusions, volcanic activity, fracturing, and faulting in the Bofecillos area probably allowed most of the previous oil and gas accumulations to escape or to be destroyed. Dietrich (1965:229) and McKnight (1968:143) suggest some possibilities for prospecting, but at best it seems that the Bofecillos area is one of high exploration risk. There is probably a much better chance of finding natural gas than there is of finding petroleum, but the remoteness from existing pipelines would tend to make small discoveries uneconomical to develop.

Fluorspar

Fluorspar is a basic raw material in the chemical, metallurgical, and ceramic industries. The numerous deposits of fluorspar that exist in Trans-Pecos Texas have been described by McAnulty (1974). Several occurrences are known to exist south of the Solitario, on the east side of Fresno Creek (McAnulty 1974:12; Fig. 5).

Fluorine is a characteristic constituent of some alkaline magmas, and almost all commercial deposits appear to have formed directly or indirectly from fluids of magmatic origin. Commercial deposits are known in all types of host rocks as void filling and as replacement veins along faults, fractures, shear zones, breccia pipes, and other brecciated areas; as irregular-shaped replacement bodies in contact zones, and as extensive concordant replacement deposits (mantos) in limestones and calcareous shales. Weathering of primary deposits sometimes results in residual deposits of gravel spar (McAnulty 1974:2-3).

Since most of the commercial deposits of fluorite in the Big Bend occur in limestones, the most favorable areas to prospect would be in the limestone outcrops in the immediate vicinity of igneous intrusions in the Solitario and the Contrabando Lowland along Fresno Creek. Ore bodies may also exist in the limestones beneath the volcanic rocks of the Bofecillos Mountains.

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The preservation of the natural state of the Bofecillos Mountain area is a result of the wise management practices of Big Bend Ranch and the Diamond A Cattle Company, who not only allowed but encouraged our study of the area. They have taken great pride in the uniqueness of this area and have recognized the exceptional value of the Bofecillos Mountains as a natural outdoor laboratory. Many geologists and geology students have been warmly welcomed on the ranch in the past, and on numerous occasions the Big Bend Ranch has expended considerable effort to facilitate the study of the area and the use of the ranch for educational purposes. This has included, but has not been limited to, the preparation of many miles of rough ranch roads to allow ingress by buses and, in the case of our study, bulldozer preparation of the Fresno Canyon road prior to our work.

The assistance of all those involved with the ranch, R. R. Anderson, R. B. Anderson, Joe Mims, Mark Davis, numerous ranch hands, and especially Ralph Hager, the ranch foreman, was greatly appreciated. Ralph was particularly generous with his help. He not only provided a great deal of information about the area but also supplied occasional equipment and assistance at times of vehicle malfunction and was a source of good fellowship as well. Ralph additionally spent several days with the field team, assisting with the data gathering and the acquisition of field collections. I think that all of the members of the Natural Area Survey field party learned to share the love and appreciation of this area held by the owners and workers on the Big Bend Ranch. We are grateful to have had the opportunity.

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APPENDIX 1

TERTIARY STRATIGRAPHY

(modified from McKnight 1968:22-104)

DEVELOPMENT OF STRATIGRAPHY AND NOMENCLATURE

Classification and nomenclature of Tertiary strata in the Bofecillos Mountains are based largely on earlier mapping in adjacent quadrangles to the north and mapping in the Big Bend National Park to the southeast.

Buck Hill area. - Goldich and Elms (1949) began the systematic and detailed investigation of volcanic strata with their report on the Buck Hill Quadrangle (Fig. 13) to the north of the Bofecillos Mountains. They defined the entire Tertiary section as the Buck Hill "Volcanic Series," an aggregate of more than 600 m of tuff, lava flows, and associated sedimentary rock which unconformably overlies marine Gulf strata. They named four formations in the Buck Hill Group (Fig. 13):

Mitchell Mesa Rhyolite–now known to be ash-flow tuff.

Duff Tuff–tuff and minor sedimentary rock.

Cottonwood Springs Basalt

Pruett Formation–tuff, associated sedimentary rock and lava flows.

Before publication of Goldich and Elm's definition and description in 1949, Goldich and Seward (1948) extended the Buck Hill Group to include rocks that overlie the Mitchell Mesa Rhyolite in areas adjacent to the Buck Hill Quadrangle. In the Tascotal Mesa Quadrangle to the southwest, they defined two formations above the Mitchell Mesa. Thus, the Buck Hill Group in this Quadrangle became:

Rawls Basalt–mostly trachybasalt porphyry flows.

Tascotal Formation–tuff and associated sedimentary rock.

Mitchell Mesa Rhyolite

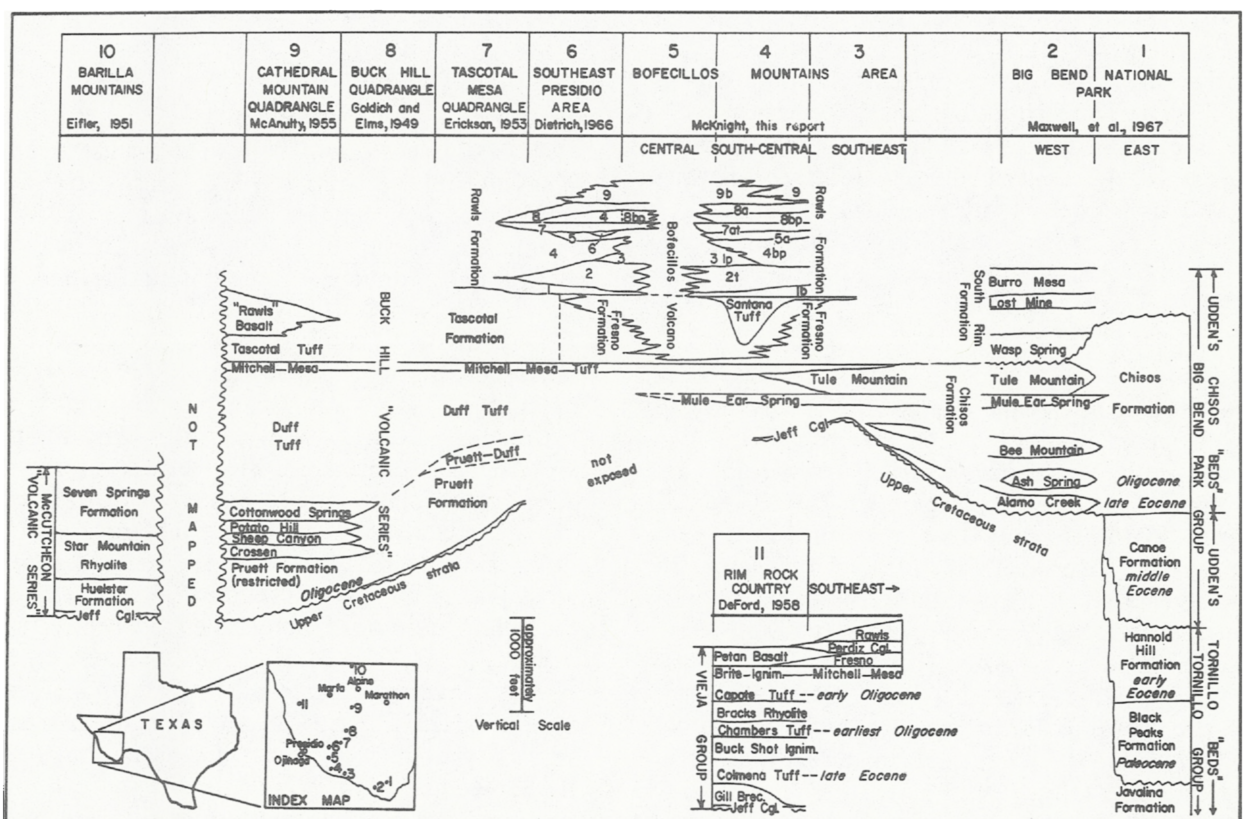


FIGURE 13

Tertiary volcanic strata mapped by various workers in Trans-Pecos Texas. (From McKnight 1968: Fig. 6)

Duff Tuff

Pruett Formation

Cottonwood Springs Basalt thins southward in the Buck Hill Quadrangle and is not present in the Tascotal Mesa Quadrangle.

Goldich and Seward (1948), Goldich and Elms (1949), Erickson (1963), and McAnulty (1955) demonstrated considerable lateral variation of the units of the Buck Hill Group. Cottonwood Springs Basalt and three members of the Pruett Formation—Crossen Trachyte (oldest), Sheep Canyon Basalt, and Potato Hill Andesite—thicken so markedly to the north that McAnulty mapped them each as a separate formation in the Cathedral Mountains Quadrangle and restricted the Pruett Formation to the section below the Crossen Trachyte. Because these lava flows are absent south of the Buck Hill Quadrangle, Erickson mapped a broad Pruett-Duff transition zone between the Pruett and Duff Formations in the Tascotal Mesa Quadrangle. Furthermore, because the Rawls Basalt thickens, he divided this formation into four units. Working to the west of Erickson, on the northwestern end of the Bofecillos Mountains, Dietrich (1965) mapped nine members in the Rawls Formation. According to Dietrich (1965:131-132), rock mapped as "Rawls Basalt" in the Cathedral Mountains Quadrangle (McAnulty 1955) and the Rawls Formation of the Bofecillos Mountains vent have different source areas and the basalt of the Cathedral Mountains should perhaps be given a different name. Similarly, Dietrich stated that some of the "Rawls Basalt" described by Goldich and Seward (1948) and subsequent workers (Davis 1961; Ramsey 1961), northwest of the Jordan Gap Quadrangle, originated from vents to the west and should more properly be termed Petan Basalt.

Big Bend National Park. – In the Big Bend National Park, the Aguja Formation grades upward into a section of variegated clay, sandstone and conglomerate, which is in turn overlain by volcanic and associated sedimentary strata. Udden (1907) applied the name "Tornillo beds" to the lower, nonvolcanic section and "Chisos beds" to the upper, volcanic section; he thought the Tornillo beds were uppermost Cretaceous, and the Chisos beds Tertiary. From a study of vertebrate fossils, however, Wilson and others (1952) demonstrated that the age of the upper part of the Tornillo is Tertiary. Maxwell and others (1967) redefined the Tornillo and raised it to group status; it includes (Fig. 13):

Hannold Hill Formation (Early Eocene)

Black Peaks Formation (Paleocene)

Javalina Formation (Cretaceous)

Maxwell and others (1967) termed volcanic and associated strata above the restricted Tornillo Group, the Big Bend Park Group, consisting of:

South Rim Formation (Oligocene?)

Chisos Formation (redefined), (Late Eocene and Oliogocene?)

Canoe Formation (Middle Eocene)

The Canoe Formation consists of volcanic conglomerate, sandstone, tuff, and a few basalt flows. It has not been formally subdivided.

On the eastern side of the Chisos Mountains, in the Big Bend Park, the Chisos Formation of Maxwell and others consists of tuffaceous sandstone, tuff, tuffaceous sandstone, and conglomerate. To the south and west of the Chisos Mountains, the Chisos Formation contains a greater percentage of tuft and several units of distinctive volcanic rock. Maxwell and others (1967) named five members:

Tule Mountain Trachyandesite Porphyry

Mule Ear Spring Tuff

Bee Mountain Basalt

Ash Spring Basalt

Alamo Creek Basalt

The South Rim Formation rests unconformably on Chisos and lower strata, and consists of lava flows, tuff, and conglomerate. Maxwell and others (1967) named three members:

Burro Mesa Riebeckite Rhyolite

Lost Mine Rhyolite

Wasp Spring Flow Breccia

Bofecillos Mountains. – A reconnaissance study of Maxwell and Dietrich (1971) through the Bofecillos Mountains revealed the relationship of the Chisos Formation to the Buck Hill Group. Throughout most of the map area, the Mitchell Mesa Tuff rests directly above, or a few feet above, the Tule Mountain Trachyandesite Porphyry, the highest member of the Chisos Formation, although at one place Maxwell and Dietrich (1965:26) reported approximately 38 m of sedimentary strata between the top of the Tule Mountain Member and the bottom of the Mitchell Mesa Tuff. In the Park, a maximum of about 120 m of tuff and associated sedimentary rock in the Chisos Formation overlie the Tule Mountain Member, but at most places the overlying South Rim Formation rests on Tule Mountain Trachyandesite Porphyry or lower strata.

A basal conglomerate of the Pruett (Jeff) is present in the Buck Hill and Tascotal Mesa Quadrangles and what is probably the same conglomerate is present in the Bofecillos Mountains Area. At the eastern edge of the area, the conglomerate is overlain by Alamo Creek Basalt, the lowest member of the Chisos Formation in the Park. Therefore, based upon nearly equivalent tops and bases, the Chisos Formation of the Big Bend Park is very nearly equivalent to the Pruett and Duff Formations of the Buck Hill Group.

From their reconnaissance, Maxwell and Dietrich (1971) define the Bofecillos Group as consisting of:

Rawls Formation
Santana Tuff
Fresno Formation
Mitchell Mesa Tuff
Chisos Formation

They replaced the name "Tascotal" with "Fresno" because the stratigraphic interval between Mitchell Mesa and Rawls in the Bofecillos Mountains is largely lava flows–quite different from the Tascotal Formation at its type locality in Tascotal Mesa. The Santana, an ash-flow tuff, is present in the southern part of the Tascotal Mesa Quadrangle and thickens markedly to more than 150 m near the Rio Grande.

This report follows the formation nomenclature of Maxwell and Dietrich (1971) except that the Jeff Conglomerate at the base of the Tertiary section is mapped separately (Fig. 14). Maxwell and Dietrich extended from the Big Bend Park the four formal members mapped here in the Chisos Formation–Alamo Creek Basalt, Bee Mountain Basalt, Mule Ear Spring Tuff, and Tule Mountain Trachyandesite Porphyry. Dietrich's (1965) informally numbered subdivisions of the Rawls Formation are adopted here, with slight modification as members. Further subdivision of formations and members record local complexities in the stratigraphy of the Bofecillos Mountains Area.

JEFF CONGLOMERATE (Tj)

Description. – The name "Jeff" is applied to a conglomerate at the base of the Tertiary which is correlated in this report with the Jeff Conglomerate of Eifler (1951) in the Barilla Mountains about 160 km to the north. In the Bofecillos Mountains Area, the formation lies with angular unconformity on Gulf rocks. Where observed, relief on the base of the Jeff is less than one meter in 30 or more meters of laterally exposed contact. The Jeff is exposed in the erosional lowlands nearly everywhere the base of the lower Chisos Formation is exposed. The presence of Jeff at depth near the center of the Bofecillos Volcano is documented by an outcrop of Jeff in Rancherias Dome. Elsewhere in McKnight's (1970) map area the base of the Tertiary section is covered by younger volcanic rocks.

The rock is a conglomerate of well-rounded limestone cobbles and boulders with interbeds and lenses of sandstone. Largest boulders are 30 cm in diameter; average diameter is about 15 cm. Interstitial to the boulders is well-cemented sandstone; the rock commonly breaks across boulders rather than around them. Bedding in the conglomerate is faint or absent, but bedding and cross-bedding are common in the sandstone. The formation ranges from less than a meter to 6 m thick.

The limestone boulders and pebbles look like Comanche Del Carmen, Santa Elena, and Buda Limestones exposed on the Terlingua Monocline and in the Solitario, but, because the fragments are uniformly well rounded, the source was probably more distant. In most places, the Jeff contains no igneous pebbles at all, but in a few places, particularly in Fresno Canyon, it contains weathered, rounded, vesicular pebbles of igneous rock up to 15 cm in diameter. Angular pebble- to boulder-size fragments of petrified wood are abundant (up to 5%) at a few localities; elsewhere petrified wood is absent.

Correlation. – The Jeff Conglomerate extends over much of the Big Bend region of West Texas. Zimmerman (1950) and Barnhill (1950) traced it from its type locality in the Barilla Mountains to the northern Davis Mountains, and Brand and DeFord (1962) reported it near the southwestern corner of the Kent Quadrangle. DeFord (1958) and subsequent workers correlated it with the basal conglomerate in the Rim Rock Country. Eifler (1951) suggested correlation of Jeff Conglomerate with the basal conglomerate of the Pruett Formation, described by Goldich and Elms (1949) and later workers. Closest reported outcrops of the two conglomerates are 90 to 100 km apart; mapping in the area between the two outcrops is incomplete, and future workers in the southern Davis Mountains may find other outcrops of similar conglomerate. On the basis of nearly identical descriptions of the basal conglomerate by Goldich and Elms (1949) and Eifler (1951), Eifler's correlation is probably valid and, therefore, the name "Jeff" can reasonably be extended into the Buck Hill area. The extension of Jeff Conglomerate into the Bofecillos Mountains from the Buck Hill area requires correlation of outcrops separated about 25 km across the Solitario, because the stratigraphic interval of the conglomerate is not exposed on the flanks. This correlation is almost certainly valid, on account of the similarity of rock type and of overlying and underlying strata.

Areal extent and environment. – If the above correlations are correct, the Jeff Conglomerate is exposed in the Bofecillos Mountains, in the Davis and Barilla Mountains, in the southern part of the Kent Quadrangle, in the Rim Rock Country, and an undetermined distance into Mexico. It was probably a nearly continuous gravel sheet which covered much of West Texas before the major accumulation of volcanic strata and associated sedimentary rock. The gravel was probably left as a residuum on a planation surface that surrounded local topographic highlands. Jeff Conglomerate is not preserved and possibly was not deposited: in the Cathedral Mountain area (McAnulty 1951); on a northwest-trending ridge between the north-central part of the Presidio Area (Dietrich 1965) and the Pinto Canyon Area (Amsbury 1957); on the Terlingua Monocline and the Solitario Uplift (McKnight 1968); elsewhere to the northwest and west of the Bofecillos Mountains. These areas were probably topographically high and may have served as sources of detritus for Jeff and later conglomerates.

Poor sorting, lack of bedding, and heterogeneous distribution of sandstone lenses in the Jeff suggest a fluvial environment of deposition. Eifler (1951:344) observed that "the thickness is uniform over too great an area for the deposit to be a piedmont alluvial fan, although the sandstone and gravel might have been spread very thin in front of a piedmont fan." Great areal extent and lack of relief on the base of the Jeff preclude origin from activity-downcutting streams in the manner of stepped terrace or pediment gravels like those in the west today. Probably the Jeff was the deposit of planing streams on a giant, gently sloping pediment surface that developed by prolonged erosion of streams at or near base level. Stokes (1950) invoked this mechanism to explain similarly thin and extensive Mesozoic conglomerates on the Colorado Plateau.

Such a gravel is not necessarily everywhere isochronous. The gravel may have been buried in one area while reworking continued elsewhere. For example, reworking and deposition of gravel up the slope of the pediplane probably persisted longer than did reworking and deposition of gravel down the slope, where it was presumably more susceptible to burial. Furthermore, on a local level, gravel being deposited in the channel of a laterally-planing stream is younger than gravel laid down by the same stream when the channel was at a different place.

Lateral planation of streams offers an explanation for local variations within the area in the constituent fragments of the Jeff Conglomerate. Igneous rock fragments were probably added to the streams which formed the Jeff Conglomerate at the beginning of eruptive activity. Before earlier, nonvolcanic parts of the gravel could be reworked, the entire gravel sheet was buried by aggrading volcanic and associated sedimentary deposits.

Sporadic occurrence of petrified wood may be explained by a similar mechanism. Silica for petrification was probably readily available only after volcanic activity began; soon after, before much reworking of the gravel, woody vegetation was probably eradicated by deposition of toxic volcanic debris. The petrified wood now found in the Jeff Conglomerate was probably deposited by streams that existed after volcanism began but before vegetation was exterminated. Lack of petrified wood in the overlying Chisos Formation supports this hypothesis.

Paucity of log-sized fragments of petrified wood and lack of silicification of the matrix of the Jeff around fossilized wood suggest that the wood was petrified before deposition, but angularity of the fragments suggests that they were not transported very far. Perhaps streams were clogged with volcanic debris before the petrified wood could be transported far enough for rounding to occur.

Igneous rock fragments are reported in the conglomerate at the base of the Pruett in the Buck Hill Quadrangle (Goldich and Elms 1949) but they are not reported in similar conglomerates in the Barilla Mountains, the northern Davis Mountains, or the Rim Rock Country; perhaps extrusive activity in these areas began after the Jeff was buried by pyroclastic detritus blown from distant sources.

Goldich and Elms (1949), Eifler (1951), and other workers in the northwest of the Bofecillos Mountains reported quartzite pebbles in the Jeff or its equivalent in their respective areas. Absence of quartzite in the Jeff of the Bofecillos Mountains Area suggests a different source area.

CHISOS FORMATION

The type locality of the Chisos Formation as redefined by Maxwell and others (1967) is in the Big Bend National Park, where it includes undifferentiated tuff and sedimentary rock and five formally-named members:

Tule Mountain Trachyandesite
Mule Ear Spring Tuff
Bee Mountain Basalt
Ash Spring Basalt
Alamo Creek Basalt

Of these, all but the Ash Spring Basalt were extended into the Bofecillos Mountains by Maxwell and Dietrich (1971). In this report, two local units of nonmarine limestone, several basalt flows, an unmapped welded tuff, and an unmapped silicified microcrystal tuff are discussed separately but not given formal member status.

Most of the area underlain by Chisos Formation in the Bofecillos Mountains is in the erosional lowlands; the upper part is also exposed in several of the intrusive domes. Thickness is difficult to determine at most places because the formation is extensively slumped. The thickest exposed section in the map area is at the east end of Lajitas Mesa, where Maxwell and Dietrich (1971) measured 323 m. The formation thins over domes of the Contrabando Lowland as a result of uplift during deposition; it is about 200 m thick in a cliff on the southeast flank (Appendix 3). To the north, in Fresno Canyon, the Chisos thins and in some places pinches out against the flanks of the Solitario Dome and Terlingua Monocline, probably in part because of nondeposition and in part because of erosion prior to the deposition of overlying rock. Although a complete section is not exposed to the west, one exposure within the breached Tapado Dome has more than 150 m of Chisos strata; probably the Chisos Formation is about 150 to 250 m thick over most of the western part of the map area.

Age

The only fossil collected in this study from the Chisos Formation was a poorly preserved gastropod, useless for significant age determination. According to Maxwell and others (1967), fossils collected from the Chisos Formation of the Big Bend Park are insufficient to date the beds precisely:

> From the stratigraphic position of the Chisos Formation, however, it is most likely that the basal units are Middle Eocene and the upper sequence, from the base of the Bee Mountain Basalt to top of the formation is Upper Eocene. (p. 136-137)

They also reported (p. 137) the potassium-argon radiometric age determinations reproduced here in Table 4.

As indicated in the text, ongoing work by Dr. Fred McDowell at The University of Texas at Austin should result in new and better radiometric age determinations for all the Trans-Pecos volcanic series.

Chisos Formation, undifferentiated (Tc)

Rock designated in this report as undifferentiated Chisos consists of variegated and laterally discontinuous slightly to moderately indurated volcanic conglomerate and sandstone, tuffaceous mudstone, and tuff.

The thickest single deposits are conglomerate beds, which range from less than 30 cm to about 30 m thick; several superposed conglomerate beds may total 10 cm, although lenses of sandstone or mudstone less than 30 cm thick and as much as 3 m in outcrop length are commonly included. The matrix is buff, gray or gray-green calcareous tuffaceous sandstone. In the conglomerate the largest fragments are boulders of volcanic rock which are angular or rounded with a maximum diameter of about 60 cm. Most conglomerate beds, however, contain 40% to 95% well-rounded cobbles and boulders of limestone and cherty limestone with a maximum diameter of 40 cm; the rock resembles Cretaceous limestone in areas adjacent to the Bofecillos Mountains, but it may be from more distant sources.

TABLE 4

Potassium-argon age determinations of Chisos lava flows in Big Bend National Park (modified by McKnight from Maxwell and others 1967)

Unit	Millions of Years
Tule Mountain Trachyandesite	28.4, 28.8 (Ave. 28.6 ± 1.5)[a]
Mule Ear Spring Tuff	30.8, 31.7, 32.1 (Ave. 31.5 ± 2.0)[a]
Bee Mountain Basalt (probable argon loss)	21.7, 23.5 (Ave. 22.6 ± 1.0)[a]
Ash Spring Basalt	32.4, 34.8 (Ave. 33.6 ± 1.5)[a]
Alamo Creek Basalt	40.1, 44.3 (Ave. 42.2 ± 2.0)[a]
Alamo Creek Basalt	38.7[b]
Alamo Creek Basalt	42.7[c]

Sources:

[a]J. H. Halsey, Socony Mobil Oil Co., Dallas, Texas (personal communication to Maxwell and others, April 3, 1964).

[b]J. F. Evernden, University of California, Berkeley (personal communication to Maxwell and others, May 9, 1963).

[c]Data on Plagioclase concentrate from G. H. Curtis, University of California, Berkeley.

Sandstone occurs in beds and lenses up to 2 m thick, and superposed beds may form units up to 10 m thick; cross-bedding is common. Colors are mostly white, gray, gray-green, or buff, but some sandstone is pink or red. The rock is poorly-sorted volcanic arkose of variable composition. Major constituents are angular, slightly to thoroughly weathered, feldspar and angular unaltered quartz cemented by hematite-limonite, clay minerals, and calcite. Minor mineral constituents include slightly hematitic flakes of biotite, opaque mineral grains, and celadonitic and hematitic crystals of pyroxene and amphibole. Lithic fragments are common in coarse-grained sandstone; most are rounded limestone fragments, but a few are angular to rounded fragments of aphanitic igneous rock, now weathered to hematite, celadonite, and clay minerals.

Mudrock beds are mostly less than 30 cm thick, but sedimentary layers consisting dominantly of mudrock are commonly 15 m to 20 m thick and, in some places, up to 40 m thick. Bedding of mudrock tends to be more continuous laterally than that of sandstone or conglomerate. Colors are commonly red-brown or gray-green, but may be buff, gray, white, black, purple, or pale green. Silt-size grains are mostly quartz and kaolinized feldspar; the matrix is hematitic and limonitic clay minerals and calcite. Hematitic biotite flakes and opaque mineral grains in small percentages are common.

The sequence of conglomerate, sandstone, and mudrock probably represents a fluvial environment of deposition: conglomerate and sandstone represent channel deposits, whereas the mudrock is a floodplain or overbank deposit.

Variegated red, gray-green, gray, white, buff, or yellow tuff is present throughout the Chisos; the upper half of the formation is mostly tuff. Most is either nonbedded or faintly bedded. A few zones up to 10 m thick are well bedded, and commonly have mud-cracked beds less than 5 cm thick; these zones were probably deposited in local ponts or lakes. Hollow tubes less than 0.2 cm in diameter, abundant in some parts of the section, are probably relict root holes.

The rock is mostly dull, but where cemented by silica it is porcelaneous. The grain size is generally fine to medium; except for sparsely distributed pumice fragments up to 5 cm in diameter, the coarsest grains are mostly less than 0.5 mm across. In a few places all grains are less than 0.05 mm in diameter. Rigg and Gould (1957) demonstrated that the grains of an ash bed originating from Glacier Park, Washington, decrease in size away from the vent; perhaps the source of the fine tuff beds in the map area had a source so distant that all but the finest particles had previously settled out.

In general, stream-laid sedimentary rock—conglomerate, sandstone, and mudrock—predominates in the lower part of the Chisos Formation; the upper half is predominantly tuff. This upward gradation is probably the result of continued or increased deposition of pyroclastic material which increasingly disrupted streams by choking them with more pyroclastic material than they could carry.

Nonmarine Limestone (Tcls)

Two beds of white, cream, or gray-mottled-and-burrowed nonmarine limestone crop out in the lower 20 m of the Chisos Formation in a breached dome about 3 km southeast of Rincon Mountain in Fresno Canyon. The lowest is up to a meter or more thick and massive, and lies immediately above 6 m of Jeff Conglomerate. The upper bed, up to 8 m thick, overlies 8 m of undifferentiated Chisos tuff, sandstone, and mudrock above the Jeff. It contains layers from less than 2 cm to about a meter thick. The rock is mostly structureless micrite, but patches of sparry calcite fill in voids, probably where the semi-consolidated ooze was disturbed by burrowing animals or plant roots. Broken calcite shell fragments, some recognizable as gastropod forms, are abundant in some zones. Several layers in the rock are mud-cracked and filled in by sparry calcite. These limestone beds were probably deposited in intermittent ponds or small lakes.

Alamo Creek Basalt (Tcac)

Maxwell and Dietrich (1971) extended the Alamo Creek Basalt Member into the Bofecillos Mountains from its type locality along Alamo Creek to the Big Bend National Park, where it was named and described by Maxwell and others (1967). It crops out on the south and southeast faces of Lajitas Mesa where the maximum thickness is about 30 m. If it is present on the north face, it does not crop out because the slope is extensively slumped and largely covered by colluvium; it thins markedly to the west along the south slope and is absent from the west face. The westernmost exposure in the map area is a small outcrop in the southeastern part of the Contrabando Lowland, near the mouth of Contrabando Creek, where the member is less than 2 m thick.

On the south face of Lajitas Mesa, the Alamo Creek Basalt is a single flow about 28 m thick (see measured section, McKnight 1968, measured section 1; reproduced in Deal 1976a: Appendix 1). A basal flow breccia less than 1 m thick includes fragments of sandy clay and tuff up to 25 cm across. Both inclusions and basalt contain abundant calcite amygdules. The basalt is thoroughly altered to a gray-green granular rock that weathers red-brown. A cliff-forming basal collonade 10 m thick overlies the flow breccia; in most places the columns do not extend to the base of the flow. Rock in the lower meter of the collonade is yellow-brown to gray-green and granular from intense alteration; it grades through a zone less than a meter thick to fresh basalt above. The relatively non-resistant entablature is about 12 m thick; the upper 3 m are altered and contain abundant amygdules of chalcedony and moss agate. A false collonade is 4 m thick, but columns are poorly defined because of intense alteration which has made the rock dark gray or black; the lower 3 m support a nearly vertical cliff, and cliffs are steep in the upper 2 m, although the rock is distinctly less resistant. Amygdules are abundant in the false collonade; most are composed of calcite and celadonite, but a few contain silica. Above the false collonade the upper 3 m of the flow are a black to dark-gray, crumbly, sand- to gravel-size rubble of thoroughly-altered, highly-amygdaloidal basalt, with calcite-filled interstices and vesicles.

The dark-gray rock including the amygdaloidal zone at the top of the flow was not thin-sectioned, but by analogy with similar rock in the Bee Mountain Basalt, the alteration probably resulted from extensive redistribution of components. The interstitial material is probably opaque minerals; other products either migrated into amygdules or upward into the rubble at the top of the flow.

Bee Mountain Basalt (Tcbm)

The type locality of the Bee Mountain Basalt Member is on the west side of Bee Mountain in the Big Bend National Park, where Maxwell and others (1967) named and described it. Maxwell and Dietrich (1971) extended it into the Bofecillos Mountains. It crops out in Lajitas Mesa, South Lajitas Mesa, and in the hills within a mile north of the Rio Grande between Fresno Creek and Madera Canyon. It is almost continuously exposed along the Rio Grande in Mexico between Lajitas and Madera Canyon. It does not crop out north or west of the Contrabando Lowland although a complete section of Chisos is exposed there. Nor is it present in Panther or Tapado Domes—the only places west of Madera Canyon where the lower part of the Chisos Formation is exposed. It probably pinches out within a few miles north of the Rio Grande and within a mile west of Madera Canyon.

The Bee Mountain Basalt generally thins westward, but the thickness ranges locally by as much as 30 m because of relief on the surface over which it spread. In Lajitas Mesa and north of Lajitas it is a maximum 80 m thick; in the cliff east of Contrabando Creek, 60 m; 3 km east of Santana Mesa, 30 m. Outcrops to the west are sporadic; probably the flow followed pre-existing stream valleys, but did not cover the interfluves.

A representative section of the Bee Mountain Basalt is immediately north of Texas Route 170 near Lajitas. At this place the unit crops out continuously for 100 m or more across the southeast face of South Lajitas Mesa; it is between 46 and 67 m thick as a result of relief on the base.

At the northeastern end of South Lajitas Mesa (section measured by McKnight 1968, measured section 2; reproduced in Deal 1976c: Appendix 2) the Bee Mountain Basalt is 60 m thick and is made up of three zones:

1. The lower 23 m of the basalt are highly vesicular and, in places, scoriaceous. A few lenses up to 60 cm thick and 6 m in outcrop length are nonvesicular. Chalcedony and moss agate amygdules, some containing calcite, are common; the largest are about 10 cm across. The rock is mostly altered; weathering of the altered rock produces rounded blocks 15 to 60 cm across and a coarse, black, pebble-size rubble.
2. The next 31 m is nonvesicular basalt. It weathers into angular, red- to yellow-brown fragments up to 15 cm in diameter. The zone is unaltered near the base but deuteric or post magmatic alteration is progressively more intense upward; the upper 10 m are thoroughly altered. The upper 5 m contain veins of moss-agate-bearing basalt which extend upward into the overlying member.
3. The upper 3 m is nonresistant moss-agate-bearing amygdaloidal and vesicular basalt with a dark-green alteration product—probably celadonite.

In this exposure, zones 2 and 3 are probably analogous to the entire flow described in the representative section; the lower 23-m zone of highly vesicular and amygdaloidal basalt is absent elsewhere.

This zonation might suggest the presence of more than one flow, but several lines of evidence suggest that the Bee Mountain Basalt is actually a single thick flow in the Bofecillos Mountains Area. Although the zones are present elsewhere in the map area, in most places the member is characteristically non-amygdaloidal or slightly amygdaloidal as in the representative section, and well zoned basalt grades laterally into non-zoned basalt. Moreover, there are no sharply defined flow bases within the unit—neither included sediment nor basal flow breccias.

Nichols (1963) described similar zonation in the Laguna and Suwanee basalt flows in the San Jose Valley, Valencia County, New Mexico, and attributed the formation of the zones to "flow-units" of relatively more fluid lava which burst through the front of the main flow and produced small lobes ahead of it that were subsequently overridden by other flow-units or the more slowly advancing main flow. In his words (p. 625):

> The existence of flow-units in the Laguna and Suwanee flows indicates complexity in the flow mechanism. The simplest type of flow is one in which the lava moves as a single unit, somewhat like a flood of water. That the Laguna and Suwanee flows moved in part in this way is indicated by the fact that many cross sections of these flows are massive and structureless. In many places, however, the mechanism of flow was more complicated. The progress of a flow is often not uniform but irregular, owing to the fact that at times the crust acts as an effective dam. With increasing hydrostatic pressure the dam, where the crust is weak, is broken and the lava is free to move. In the cases under consideration, tongues a few hundred feet wide broke out from the front and sides of a flow and flowed on for considerable distances. Crusts appeared on these lava tongues, and solidification proceeded until a degree of rigidity was attained; these tongues were buried by later tongues, which in turn were buried by others.

Mule Ear Spring Tuff (Tcm)

The type locality of the Mule Ear Spring Tuff Member is at Mule Ear Spring in the Big Bend National Park, where Maxwell and others (1967) named and described it. Maxwell and Dietrich (1971) extended it into the Bofecillos Mountains. Except in middle and upper Fresno Canyon where it is sporadically present, the Mule Ear Spring crops out as a single ash flow of nonwelded to thoroughly welded tuff wherever its place in the section is exposed. Nevertheless, outcrops are scarce because slopes are generally covered by slump blocks and landslide material from the stratigraphically higher Tule Mountain Member, but a sufficient number of outcrops are distributed throughout the map area to suggest that the Mule Ear Spring was deposited as a more or less continuous sheet over all but the northeasternmost part. Its great areal extent is remarkable because it is only 1 m to 3 m thick, except in Tapado and Fresno Canyons where it is as much as 10 m to 13 m thick. The surface of ash-fall tuff, over which the member spread, must have had slight relief.

The rock is moderately- to well-indurated, commonly porcelaneous, nonwelded to moderately-welded vitric to vitric-crystal tuff. Most constituent fragments are lsss than 3 mm in diameter, except for pumice fragments, the largest of which are several centimeters long. One of the most consistent and useful criteria for field identification is 2 to 13% glassy, feldspar crystals 1 to 3 mm long; most of them are sanidine, but 5 to 25% of the crystals are twinned plagioclase. In a typical exposure, the contact with the underlying strata is abrupt. At several places, several centimeters to a meter or more of light-gray bentonite is present at the base. Above the bentonite or the underlying strata, the rock grades in several centimeters to rock that differs in appearance from place to place because of variations in welding, devitrification, vapor phase crystallization, alteration, and coarse crystallization. In the top meter or so, the rock grades to friable, nonwelded, slightly indurated brown to gray tuff.

In a general way, welding increases with thickness, but exceptions are numerous—the tuff is slightly welded in some places where the member is less than 3 m thick, but elsewhere it lacks welding even though it is 6 m thick. Welding is greatest a meter or so above the base. At no place is the tuff welded to a basal obsidian, but at several places, the welded zone is highly eutaxitic, and shard structure is eliminated by compaction and subsequent crystallization. In these thoroughly-welded zones, white miarolitic lenses up to several centimeters long that parallel and accentuate the eutaxitic structure are made up of chalcedony or cristobalite-feldspar intergrowths similar in form to the axiolitic structure seen in devitrified shards of other samples. Some lenses are filled or replaced pumice and void spaces that were flattened during welding; others are probably the result of recrystallization of the matrix.

The appearance of the rock is greatly changed by devitrification, vapor-phase crystallization, and alteration. In many places the rock is porcelaneous as a result of extensive silicification of the matrix; radiating fibrous and colloform aggregates of chalcedony, opal, or cristobalite-feldspar intergrowths have partly filled interstices between fragments, crystals, and axiolitic devitrified shards. Zeolites or clay minerals fill the centers of many interstices, and minute grains of opaque minerals and celadonite speckle the matrix. Hematite-limonite forms rims around devitrified shards, is concentrated in and around altered dark minerals or accidental fragments, and is disseminated as a fine dust throughout the matrix; the red, red-brown, brown, pink, or orange color of the rock is dependent on type, concentration, and distribution of these iron oxides.

Microcrystal tuff (included in Tc)

A zone up to 3 m thick of silicified microcrystal tuff lies near the base of the Tule Mountain Trachyandesite and may be underlain or overlain by basalt (Tcb). It crops out along the southern edge of the map area between Lajitas Mesa and Tapado Dome. In most places this stratigraphic interval is covered by talus from the overlying Tule Mountain Trachyandesite Porphyry.

The tuff is massive, well sorted, slightly to moderately indurated, pink to brownish-pink, granular, crystal or crystal-vitric tuff; it is chalcedonic and porcelaneous in some places. It is generally homogeneous, with at most several centimeters at the base and top more friable and lighter colored than the central part. The silicification and high percentage of crystals contrast sharply with friable vitric and vitric-crystal tuffs common in the Chisos Formation. The tuff is probably of ash-fall rather than ash-flow origin because of its sorting; lack of stratification suggests that it was deposited rapidly, probably from a single ash fall.

In the Big Bend National Park, the same or a similar unit is included in the Mule Ear Spring Tuff (Maxwell, oral communication, March 1966). It is treated separately in this report because in the map area it is separated from the vitric-crystal ash flow of the Mule Ear Spring by up to 30 m of vitric ash-fall tuff typical of most of the undifferentiated Chisos Formation. Attempts to map the intervening tuff as part of the Mule Ear Spring would have been futile because of sparse outcrops of the two bounding tuffs.

Ash-flow tuff (included in Tc). — A bed of ash-flow tuff as much as 1 m thick crops out along Tapado Creek at the southwest end of Tapado Dome; it rests on conglomerate overlying the Mule Ear Spring Tuff and is overlain by the microcrystal tuff described above. It is vitric to crystal-vitric tuff similar in composition to the Mule Ear Spring Tuff.

At one place the tuff consists of two zones. The lower is a black perlitic obsidian about 30 cm thick, the upper half of which is irregularly devitrified or altered to a gray-green friable rock. This basal glass is overlain with sharp contact by 30 cm to 1 m of dark-red-brown, highly porcelaneous, eutaxitic, thoroughly welded tuff. The contact with the microcrystal tuff is jagged, with the microcrystal tuff penetrating as much as 30 cm into the eutaxitic tuff below. Absence of a nonwelded zone above the eutaxitic tuff and the jagged upper contact suggests that the nonwelded zone was removed and the microcrystal tuff injected downward into the eutaxitic zone; the cause of this relationship is not known.

About 30 m to the south, across a covered interval, the tuff is about a meter thick and consists of alternating layers of dark-red-brown, fine-grained, porcelaneous tuff and silt- and sand-size, pink, slightly porcelaneous tuff; in many places the two layers are clearly part of a single graded bed, but elsewhere the grading is less distinct or absent. Such alternating zones might have occurred if the ash-flow entered a body of water—the observed layers formed as the ash settled through the water which was made turbulent by the hot ash flow.

Basalt (Tcb)

Several flows of basalt crop out in the map area either within about 1 m below the Tule Mountain Member or, in the absence of the Tule, bracketed between the Mule Ear Spring Tuff (below) and the Mitchell Mesa Tuff (above). These flows covered small areas; they are in South Lajitas Mesa, and in Corrasco, Tapado, Llano, and Saucita Domes.

The thickest flow is in Tapado Canyon where a flow of seriate, trachytic and ophitic olivine-augite basalt in measured section 7 (Appendix 7) is 33 m thick. It consists of a lower 6-m zone of slightly vesicular and amygdaloidal basalt, a 24-m nonvesicular middle zone, and a 4-m nonresistant scoriaceous zone of thorough alteration, now mostly weathered to pebble-size rubble that is partly cemented with calcite.

A flow of red-brown to dark-gray, altered and weathered, limonitic and calcitic, trachytic iddingsite-augite basalt, up to 10 m thick, crops out immediately under the Tule Mountain Trachyandesite Porphyry on the west and south faces of South Lajitas Mesa. In the Carrasco Dome, an altered and weathered augite basalt flow crops out sporadically between the Mule Ear Spring Tuff and the Mitchell Mesa Tuff; its thickness is less than 3 m. Altered and weathered dark lava flows are exposed in the same stratigraphic position in the Llano and Saucita Domes. Thickness in the Llano Dome is less than 3 m; in the Saucita Dome it is more than 10 m, and the base is not exposed.

In the Big Bend National Park, a basalt that crops out below trachyandesite of the Tule Mountain Trachyandesite Porphyry is included within the Tule Mountain Member (Maxwell, oral communication to John McKnight, June 1966); it is petrographically distinct from the basalts in the Bofecillos Mountains Area.

Tule Mountain Trachyandesite Porphyry (Tctm)

The type section of the Tule Mountain Member is at Tule Mountain in the Big Bend National Park where Maxwell and others (1967) named and described it. Maxwell and Dietrich (1971) extended it into the Bofecillos Mountains. It crops out in the southeastern part of the map area and in several breached domes where its stratigraphic interval is exposed. The member does not crop out in Fresno Canyon north of its pinchout near Rincon Mountain or in the Llano, Saucita, and Carrasco Domes. It is present to the southeast in the Big Bend Park and it crops out in the Rio Grande Valley in Mexico at least as far west as the Santana Bolson and probably as far west as Redford. It does not crop out in quadrangles north of the Bofecillos Mountains Area. Thus, it probably pinches out south of a line due west from Rincon Mountain and against the Solitario Dome and Terlingua Monocline from the south and east.

The Tule Mountain Trachyandesite Porphyry is a cliff-forming lava flow that is normally 60 to 100 m thick; it is thickest on the northeast slope of Santana Mesa, where Maxwell and Dietrich (1971) measured 107 m. A poorly-defined orange-weathering scoriaceous basal breccia less than 30 cm thick is overlain by a vesicular zone up to a meter thick. It grades upward to green, brown, or black, nonvesicular, altered, porphyritic, intersertal, celadonitic aegirine-augite trachyandesite typical of most of the unit. The trachyandesite, particularly the upper half, exhibits a marked swirled flow structure; it tends to split along the flow foliation producing abundant spalls, which litter the slopes below the outcrop. The spalls are mostly 10 to 60 cm across, but some are as large as slump blocks. The upper 3 m are vesicular or scoriaceous and weather orange to red-brown. The Tule Mountain Member is probably a single flow.

MITCHELL MESA TUFF (Tmm)

The top of the Mitchell Mesa Tuff is one of the most useful horizons for stratigraphic correlation in the Big Bend region of Texas. A discussion of its aerial extent and origin is given earlier in the text.

In the map area, the Mitchell Mesa is a cliff-forming ash-flow tuff that lies either directly above the Tule Mountain Member or above as much as 6 m of Chisos tuff that separates the two units; it is present nearly everywhere that its stratigraphic interval is exposed. Except on the flanks of the Solitario and Contrabando Domes—areas that were probably high topographically at the time of deposition—it was probably a more or less continuous sheet over the entire map area.

The tuff is mostly between 6 and 11 m thick; maximum thickness is about 15 m. It thins markedly in the southeastern part of the map area; at two outcrops on South Lajitas Mesa it is 0.6 and 1.5 m thick; on the northeastern end of Santana Mesa it is less than 3 m thick.

The rock is moderately to well indurated, nonwelded to moderately welded vitric-crystal tuff. Unweathered rock is gray to cream or white; the unit weathers buff or red-brown. The aphanitic matrix of the rock is normally slightly porous, but the rock is nonporous and commonly porcelaneous where welded or extensively recrystallized or devitrified and cemented with silica. Phenocrysts up to 4 mm across of glassy, chatoyant sanidine and glassy quartz make up 5 to 25% of the groundmass; they are a useful guide for field identification, particularly on weathered surfaces where the crystals stand up above the more easily weathered matrix. Pumice fragments, mostly less than 1 cm but up to 10 cm across, comprise up to 10% of the rock and commonly weather away leaving lensoidal pits on exposed surfaces.

Within the lower meter or so, the rock grades upward from friable, white to buff tuff to the well indurated, resistant rock characteristic of most of the formation. Most of the rock is generally nonwelded to slightly welded, but in some places where the formation is more than 10 m thick, the rock is foliated with pronounced eutaxitic structure in a broad zone about about midway between the base and the center. The upper part is a zone of nonresistant friable tuff that may be only a meter or so thick or that may comprise more than half of the ash flow; the thickness depends on the degree of welding, devitrification, vapor phase crystallization, and alteration. Spherical caves up to 2 m in diameter are common in this zone, developed on cliffs and particularly on the rolling surface that develops on the upper part of the ash flow. Similar caves in the Valles Mountains, New Mexico, were formed by wind erosion according to Ross and Smith (1961:30):

> In the porous poorly welded zones where vapor-phase minerals have formed these minerals tend to be weakly coherent and thus they are very easily broken and vulnerable to the agents of wind erosion. This is especially true where minerals occupy former pumice fragments. Here erosion forms pits that are further enlarged until some reach cavelike proportions. Many outcrops of ash-flow tuffs in the Valles Mountains have casehardened surfaces. Erosion may start at inequalities in these surfaces especially where pumice fragments occur. This gives wind and rain access to the poorly consolidated interior and conspicuous cavities develop.

Although the Mitchell Mesa is remarkably consistent in both appearance and composition throughout most of the area, significant variations occur. In several places, notably in the two easternmost exposures in South Lajitas Mesa, it is a pink to red-brown, porcelaneous bed less than 2 m thick, composed entirely of grains less than 1 mm in diameter. Absence of coarser grains, particularly the normally abundant glassy crystals of sanidine and quartz, suggests that the rock at these localities was deposited either by a relatively nonturbulent part of the ash flow, as might exist over a local topographic high, or more probably by the ash fall associated with the Mitchell Mesa ash flow.

Another atypical sample of Mitchell Mesa, collected near the base of a 10-m layer that crops out in Saucita Dome, contains 20 to 25% of narrow laths of unaltered albite-oligoclase up to 1 mm long. In addition, the rock contains abnormally low percentages of sanidine (5%) and quartz (1%) and a high percentage of accidental fragments of altered latite. The plagioclase crystals in the latite fragments are indistinguishable from the anamalous albite-oligoclase laths, a fact suggesting a common accidental source. Probably the atypical character of this rock resulted from extensive dilution of the lower part of the ash flow by accidental material—mostly individual plagioclase laths—from the local substrate. At this locality, the Mitchell Mesa Tuff rests on Chisos tuff (Tc) or basalt (Tcb), neither of which contains narrow plagioclase laths like those observed; the main vent of the Bofecillos Volcano is only a few miles to the southwest, however, and it may have begun erupting before effusion of the Mitchell Mesa and spread the foreign material in the path of the ash flow.

FRESNO FORMATION

The Chisos and Mitchell Mesa Formations include regional volcanic units, probably from sources outside of the map area. At about the same time as the effusion of the Mitchell Mesa, however, the Bofecillos Volcano began erupting ash and latitic lava; tuff and lava flows from this source were interbedded with minor amounts of regional tuff and with local conglomerate and sandstone (Fig. 14). Extrusive activity was accompanied by intrusions; concordant intrusions domed the overlying strata, and strata deposited concurrently or subsequently were thinned or pinched out against the flanks. The Solitario was breached by the time the upper Fresno flows were extruded; the flows are interbedded with conglomerate containing rock fragments derived from within the uplift. Strata that were deposited under this complex, predominantly local regimen, are exhibited in the Fresno Formation.

As defined by Maxwell and Dietrich (1971) at its type locality in the Bofecillos Mountains, the Fresno Formation consists of strata above the Mitchell Mesa Tuff and below the Santana Tuff; where the Santana is absent, the contact is placed at the base of the lowest lava or tuff of the overlying Rawls Formation.

As would be expected, the ratio of lava flows to tuff and sedimentary rock generally decreases with distance from the center of eruptive activity—in the vent area, the Fresno Formation is almost entirely lava flows; several miles from the center, the formation is predominantly tuff or sedimentary rock, containing only a few flows near the top. A valley fill sequence and a sodic rhyolite are exposed only in the northern part of Fresno Canyon; they comprise much less than 1% of the total volume of the Fresno Formation in the map area.

The maximum thickness of the Fresno Formation in the vent area may be inferred from a 300-m section in upper Tapado Canyon 10 km southwest of the main vent. Allowing for the depositional slope of the lava flows away from the cone, the Fresno Formation in the volcanic center was probably 370 to 460 m thick before erosion. Away from the vent, the Fresno was probably about 150 to 250 m thick where not thinned over intrusive domes.

Fresno Formation, undifferentiated (Tf)

Rock mapped as undifferentiated Fresno Formation includes ash-fall tuff, eolian tuff, eolian tuffaceous sandstone, fluvial tuffaceous sandstone, and near the top, conglomerate and conglomerate sandstone. It makes up the lower part of the Fresno Formation at most places and is interbedded with some of the flows in the upper part.

Tuff and tuffaceous sandstone. – Fresno tuff is mostly friable, bedded, cross-bedded or massive sandy vitric-crystal tuff. "Root holes" like those in Chisos tuff are common. Eolian cross-beds with more than 1-m amplitude occur in zones up to 3 m thick. In most places there is no sharp break between bedded, massive, and cross-bedded zones, and there is a continuous gradation in rock type from ash-fall tuff through eolian cross-bedded tuff to eolian tuffaceous sandstone; grains, including pumice and autoclasts of tuff, are progressively better defined and many—even some of the larger crystals of feldspar and quartz—are rounded in the eolian sandstone.

The tuff is white, buff, gray, or green; pale-green to yellow-green cross-bedded tuff is characteristic of the Fresno Formation and its stratigraphic equivalent, the Tascotal Formation. The color is imparted by finely crystalline celadonite, an alteration product associated with zeolites and clay minerals; it is brightest green where it is surrounded by chalcedony, probably because the silica protected it from oxidation in the weathering environment.

Most of the fluvial sandstone interbedded with the tuff is only slightly reworked tuff or eolian sandstone. It was perhaps deposited during storms by sheet wash or rill wash off the volcano; rapid deposition of ash probably choked through-flowing streams that might have thoroughly reworked the tuff. Most of the fluvial sandstone contains a greater percentage of accidental fragments; framework grains, including poorly cemented grains of tuff, are well defined and easily distinguished from the matrix in thin section.

Gradual upward transition from ash-fall tuff, in the upper Chisos and lower Fresno to eolian sandy tuff in the Fresno Formation, probably reflects more rapid deposition of volcanic ash that smothered or poisoned soil-holding vegetation, and was then free to drift when not wet from recent rain.

Conglomerate and sandstone. – The upper part of the Fresno Formation contains abundant conglomerate and sandstone in some places interbedded with flows. Individual beds range from several centimeters to 6 m thick, and zones composed dominantly of conglomerate and sandstone are up to 4 m thick.

The conglomerate is derived from two major source areas:

1. Most eroded from the Bofecillos Volcano; conglomerate is interbedded with the flows and commonly extends farther from the vent area than the flows. Included rock fragments are mostly angular to rounded boulders and cobbles of volcanic rock eroded from Fresno flows.
2. Conglomerate eroded from the Solitario is present northeast of the Bofecillos Volcano in the upper part of Fresno Canyon. It consists mostly of rounded cobbles and pebbles of cherty Cretaceous limestone, but in the upper part of the section it also contains abundant recognizable fragments of Maravillas (Ordovician) black chert; Caballos (Devonian-Mississippian) white, green, and red-brown chert; Tesnus (Carboniferous) red-brown siliceous shale; and "Shutup" (basal Cretaceous) conglomerate. These units are described in detail by Powers (1921), J. L. Wilson (1954); Herrin (1958), and Irvin (1957).

Lava flows of Bofecillos eruptive center

The sequence of Fresno flows of the Bofecillos Volcano grades upward from latite (Tfl) to latite porphyry (Tflp); contacts between the two rock types are more or less arbitrary. Trachyandesite (Tfa) and a single flow of olivine basalt (Tfb) probably issued from fissures on or near the volcano.

Trachyandesite (Tfa). – A single distinctive flow of mafic trachyandesite as much as 110 m thick is present southeast of the vent area between Rancherias and Primero Canyons; probably the same flow, or one from the same pulse of eruption, is exposed east and northeast of the vent, north of Rincon Mountain in Fresno Canyon and in Llano and Saucita Domes. In the lower part of Fresno Canyon (measured section 4 of McKnight 1968; reproduced in Appendix 4 of this report), it is 35 m thick. At the base is a laterally discontinuous 30-cm zone of red-brown and black, banded, perhaps flow-layered glass that is either a chilled basal flow breccia, or more probably, fused tuff beneath the flow. Above the glass is a 2-m zone that grades from highly vesicular rock near the base to nonvesicular trachyandesite at the top. Most of the flow is cliff-forming, unaltered, gray, intergranular, celadonitic, mafic augite trachyandesite. The upper 6 m grades through vesicular trachyandesite to black scoriaceous rubble in the upper few feet, consisting mostly of gravel-size fragments with a few blocks nearly 30 cm across.

Latite (Tfl). – The lower flows are mostly nonporphyritic or slightly porphyritic latite. Few flows extend far from the eruptive center; thick exposures in breached domes and in deeply incised canyons belong to the lower part of the Fresno Formation near the vent.

Most flows range from 6 to 23 m thick. In general, a red-brown- to black-weathering, highly scoriaceous basal flow breccia less than a meter thick is overlain by a vesicular or amygdaloidal zone less than 2 m thick. Most of each flow is dark-gray to light-gray, nonvesicular aegirine-augite-iddingsite latite; in places olive-green limonitic celadonite mottles the rock or colors the entire groundmass. Some flows have a prominent layered or swirled flow structure and the rock weathers in curved slabs or spalls along flow laminae. A vesicular or scoriaceous zone from 2 to 12 m thick occurs at the top. Acetate peels of samples collected in upper Tapado Canyon and Rancherias Canyon (measured section 7 of McKnight 1968; reproduced as Appendix 5 of this report) indicate that the latite resembles the matrix of latite porphyries from the Bofecillos Volcano.

Latite porphyry (Tflp). – Most of the Fresno lava extruded from the Bofecillos center of eruption is latite porphyry (Tflp); the thickest flows are about 80 m thick, but most are less than 30 m thick; average thickness is 6 to 25 m; they may lie directly on other flows or on thin (unmapped) zones of tuff, sandstone, conglomerate, or volcanic mudflows. The flows are highly varied: they may erode to steep unscalable cliffs or relatively gentle vegetated slopes; they may be thoroughly vesicular or scoriaceous or the vesicles may be restricted to thin zones near the top and base; jointing may be columnar, irregular, or follow laminar or swirled flow structure—spacing between joints may be 7 cm or a meter or so; alteration or weathering may be intense or slight and differs with position in the flow; angular or rounded, weathered fragments range in size from gravelly rubble to slump blocks.

In general, the rock is intergranular or hypidiomorphic granular felted or subtrachytic, aegirine-augite or augite-iddingsite porphyry. Texture and composition range widely between flows. Although the average rock is latite, it ranges from trachyte to trachyandesite. Most rock is dark- to light-gray, but much is weathered or altered red-brown from hematite-limonite staining and some is gray-green from interstitial celadonite present either as mottling or distributed throughout the grandmass. Feldspar phenocrysts are cloudy-white or pink.

Basalt (Tfb)

A single flow of Fresno basalt crops out below the Santana south of the vent area along "Closed Canyon Creek" between Rancherias and Panther Canyons; it is as much as 30 m thick. Both in outcrop appearance and in petrography, the rock resembles basalt in the lowest member of the Rawls Formation (Trlb); it probably represents an early pulse in the phase of eruption recorded by Rawls member 1. The black rock which weathers red-brown is strongly seriate, intergranular, deuterically or post magmatically altered, slightly porphyritic, augite or aegerine-augite basalt.

Sodic Rhyolite (Tfsr)

In the middle part of Fresno Canyon, a layer of sodic rhyolite up to 3 m thick with sparse broken and partly fragmented phenocrysts of quartz, sanidine, and rarely of hornblende occurs at or near the base of the Fresno. It is overlain with sharp contact by massive tuff, and it rests on massive tuff, on Comanche limestone, or on flaggy Boquillas limestone. In some places the rhyolite is brecciated, either by flowage during emplacement or by subsequent jointing. The original groundmass texture is everywhere obliterated. The rock is mostly horizontally streaked or layered with undulose discontinuous zones of fibrous chalcedony, and perhaps zeolites in sheaflike colloform bundles; some of the layers are disrupted by stylolites. Interstitial microscopic opaque minerals, hydrated from oxides, and aegirine-augite or riebeckite, color the normally white silica gray to black, red-brown or orange, and gray-green or blue-gray.

The origin is uncertain. The rock is probably not intrusive because it rests on a structurally varied stratigraphic horizon that in some places, particularly in massive tuff, is unsuited for the emplacement of a concordant sill. It was probably not a lava flow either, because so silicic a lava would probably be too viscous to spread so thin and extensive a sheet. It is probably pyroclastic; if it were originally a volatile- and alkali-rich vitric tuff, devitrification and extensive alteration could have produced a unit with the observed composition and field relationships. Additional silica and perhaps alkalies were probably added in places by ground water; large bodies of silica mapped about a mile to the north are perhaps completely silicified sodic rhyolite.

Valley-fill sequence

Where the present road climbs out of the upper part of Fresno Canyon, a valley 120 m deep was eroded into undifferentiated Fresno tuff (Tf) and the underlying Boquillas Formation. Thereafter, it was filled before effusion of the Santana tuff by:

Tfvm, volcanic mudflow
Tfat, ash-flow tuff
Tf, undifferentiated conglomeratic sandstone
Tfvb, volcanic brecia

Volcanic breccia (Tfbr). – The massive volcanic breccia is as much as 30 m thick. It is made up of closely spaced, but not self-supporting, angular to slightly rounded, fragments of white to light-gray flow-banded rhyolite. Most fragments are 7 to 30 cm in diameter, but some range up to 2 m. The matrix consists of gradational patches of red-brown to orange and gray to white tuff-like altered rhyolite. Pumice fragments are sparse, but common lense-shaped cavities up to 25 cm long are probably pumice relicts. At several places the breccia is made up of as many as six subunits; they are vaguely defined lenses up to 20 m thick and more than 100 m across whose outlines are distinguished by changes in matrix color and induration over a vertical distance of a few tens of centimeters. Contacts between the subunits are undulose, with as much as 6 m of relief in exposures about 30 m across.

The breccia is probably a single auto-brecciated lava flow (Smith: oral communication to John McKnight Nov. 1966); the subunits were perhaps formed through differences in fluidity of the lava, which permitted some zones in the rhyolite to flow faster than other parts.

Conglomeratic sandstone (Tf). – Here and there, well-bedded conglomeratic sandstone, mapped as undifferentiated Fresno Formation, is present between breccia (Tfbr) and ash-flow tuff (Tfat); it is up to 20 m thick. In most beds, the coarsest clasts are about 8 cm in diameter, but some beds contain boulders up to 60 cm across. The matrix is tuffaceous sandstone; constituent clasts are mostly blue-gray to white rhyolite like that in the breccia below. Micritic limestone is also present, and some contains abundant fossil gastropods; black chert is sparse.

Ash-flow tuff (Tfat). – The ash-flow tuff is up to 10 m thick, and except for about 20 cm of dull-gray, friable tuff at the base and about a meter or less or similar rock sporadically present at the top, it looks the same from base to top; it is gray to white, porous, porcelaneous, nonwelded, vitric or vitric-crystal tuff with partly fragmented crystals of sanidine and quartz a few millimeters across, and with 5 to 10% lensoidal pumice fragments up to 15 cm long. It weathers orange to buff. It closely resembles the Santana Tuff; the two units may be genetically related.

Volcanic mudflows (Tfvm). – The uppermost unit of the valley fill sequence is about 60 m thick, consisting of four or more massive volcanic mudflows up to 30 m thick with interlayered volcanic conglomerate and conglomeratic sandstone; toward the top it includes a few zones of tuff up to 3 m thick and ash-flow tuff sheets up to 2 m thick laden with fragments of nonwelded pumice and flow-banded rhyolite.

The volcanic mudflows consist of angular to rounded fragments of biotite-bearing latite; they are mostly cobble-size and the largest are less than a meter across. The matrix is white to gray tuff and tuffaceous sandstone. A gradation in the upper part of some of the flows from massive breccia below to bedded conglomerate above indicates that the material was water-charged and that the upper parts were probably reworked by the runoff.

The latite of the mudflows closely resembles latite of the Bogles Domes immediately to the west and southwest. This resemblance suggests that some of the Bogles intrusions were deroofed soon after they were emplaced, and thereby supplied the blocks to the mudflows.

SANTANA TUFF (Ts)

Maxwell and Dietrich (1971) named and described the Santana tuff. The type locality is in Santana Mesa and nearby cliffs in the south-central part of the map area. It is ash-flow tuff composed of one to at least six (and probably more) partly welded ash flows. West of Santana Mesa at the mouth of Panther Canyon it is about 170 m thick. The Santana thins gradually to the northwest and pinches out across Tapado Canyon. It thins abruptly to the north and northeast, probably because of faulting before or during effusion; it pinches out over Fresno flows on the flanks of the Bofecillos volcanic cone, but extends almost to the head of Fresno Canyon as a layer mostly less than 2 m thick. Maxwell and Dietrich (1965) reported the northernmost known outcrop of Santana at the southern end of Tascotal Mesa, about 8 km north of the map area. During air reconnaissance south of the map area, Muehlberger (oral communication to John McKnight April 1966) noted that a tuff that looks like the Santana at Santana Mesa extends at least 15 km into Mexico.

The Santana forms distinctive orange cliffs; stream valleys cut into it are narrow gorges with near-vertical walls. Normally, the longitudinal profiles are uneven because zones within the Santana differ in resistance to erosion; relatively level stretches are interrupted by commonly insurmountable, fall zones up to 30 m high.

The rock is nonwelded to thoroughly welded vitric-crystal tuff; the high percentage of glassy sanidine crystals and generally low percentage of lithic fragments are, in general, sufficient to distinguish it from similar tuff in the map area. Pumice fragments up to 5 cm across are abundant; however, some range up to 30 cm in diameter. Where nonwelded it is friable, dull, porous, gray, buff, or white devitrified tuff with interstitial zeolites and clay minerals. The nonwelded material grades to well indurated porcelaneous pink or dark-red-brown rock. The induration is probably the result of a complex interaction of devitrification, vapor-phase crystallization, and deuteric alteration of dark minerals, characteristic of the nonwelded zone of vapor-phase crystallization of Smith (1960b), although secondary chalcedony, opal, zeolites, and clay minerals commonly predominate in the rock over vapor-phase minerals. Most of the welded tuff is thoroughly indurated, porcelaneous rock, that is slightly to intensely eutaxitic; it probably corresponds to Smith's partly welded zone of vapor-phase crystallization, although some may be devitrified vitrophyre of his zone of dense welding.

Where the Santana is less than 30 m thick, it is mostly a single cooling unit and probably a single ash flow. A friable nonwelded zone at the base, a few tens of centimeters thick, grades upward to the vapor-phase zone of nonwelded tuff. Where the Santana is more than 15 to 20 m thick eutaxitic structure indicative of slight to moderate welding is common in a zone beginning 3 to 6 m above its base; the structure grades from faint at the top and bottom of the zone to moderate or intense near the center. The thickness of this zone increases with thickness of the unit as a whole; it is overlain by the 6- to 15-m upper nonwelded zone of vapor-phase crystallization. The upper 2 to 15 m of the Santana is friable nonwelded tuff like that at the base.

The Santana is more than 30 m thick only in the south-central part of the map area. There it is mostly one or two compound cooling units consisting of alternating gradational layers of nonwelded, slightly, moderately, or intensely welded tuff; in fact one to six or more ash flows and two cooling units may be inferred in some places (measured section 5 of McKnight 1968; reproduced in Deal 1976c, Appendix 3).

The source of the Santana Tuff is probably in

Mexico south or southwest of Santana Mesa. The Santana thickens and the number of ash flows increases in that direction, probably because contemporaneous faulting or folding formed a topographic basin there. Perhaps the roof collapsed into its own magma chamber and the magma was displaced as pyroclastic material upward into the depression thus formed. The body of rhyolite porphyry (Tirp) at the southeastern end of Santana Mesa is similar in composition to the Santana; it may be an intrusion associated with the Santana vent area.

RAWLS FORMATION

At about the same time that the Santana Tuff was spread, volcanic eruption in the Bofecillos Mountains became more complex. In addition to latite porphyry and latite from the Bofecillos Volcano, trachyandesite, basalt and basalt porphyry flowed out, probably from fissures in and around the eruptive center. Moreover, ash-fall and ash-flow tuff layers were spread over the area, probably from vents within or nearby the map area. Block faulting began extrusion of the uppermost basalts which are interbedded with graben-filling sedimentary rock. A maximum of about 380 m of volcanic and associated strata were deposited, but the section is thinner over topographically high areas—for example, over intrusive domes and over the Fresno flows of the Bofecillos Volcano. The Rawls Formation is the stratigraphic record of the interfingering of units of these diverse volcanic rock types.

Goldich and Seward (1948) named the Rawls Formation to comprise the lava flows capping Tascotal Mesa which overlie sedimentary and pyroclastic rock of the Fresno-equivalent Tascotal Formation. As redefined by Maxwell and Dietrich (1971) and as used in this report, the Rawls includes volcanic and associated sedimentary strata in the Bofecillos Mountains that lie above the Santana Tuff. In the absence of Santana, the base of the Rawls is the lowest lava or tuff unit that overlies the Santana.

In the map area, McKnight's report (1968) modifies and extends Dietrich's (1965) nomenclature of units within the Rawls to reflect the increasing complication of the Rawls Formation in the Bofecillos Mountains Area (Figs. 13 and 14). Thus, McKnight divides the Rawls into nine numbered members. Except for member 8, each member represents a major pulse of eruption characterized by the rock types marked with asterisks in Table 5; member 8 is characterized by two asterisked rock types.

Numbers of members are used ordinally; *ascending* stratigraphic position is indicated by higher numbers. It is possible, however, to move *laterally* in the stratigraphic section from a higher to a lower number (Fig. 14). Subdivisions of members indicate *only* the rock type—no stratigraphic position is implied, and indeed, the same rock type may be found at several stratigraphic positions within a member.

Member 1

The lowest member of the Rawls Formation consists of as many as six basalt flows, and interbedded volcanic conglomerate, sandstone, and tuff. A few flows of trachybasalt porphyry (Trlbp) like that of member 4, and thick sequences of undifferentiated sedimentary rock and tuff (Trl) are mapped separately. Most flows are 3 to 10 m thick; maximum thickness is about 15 m. The maximum thickness of basalt flows and interbedded sedimentary rock is about 50 m near the mouth of Rancherias Canyon (McKnight's measured section 7, reproduced in Appendix 5 of this report), but in most places it is less than 23 m thick. The member thins toward the northeastern boundary of the map area, and pinches out against Fresno flows both on the Bofecillos volcanic cone and on the flanks of the Solitario.

At the mouth of Bofecillos Canyon, member 1 (McKnight's measured section 12; reproduced in Appendix 10 of this report) is a single flow about 15 m thick. The upper 1 to 2 m of pale-buff tuff over which it spread is altered pink probably by the hot lava. A sporadically present basal flow breccia up to 30 cm thick is composed of a matrix of tuff with scoriaceous black basalt fragments up to 13 cm across. Above the breccia is a red-brown- to pink-weathered zone up to 30 cm thick that grades upward to a black unweathered basalt. Most of the flow is black homogeneous to slightly amygdaloidal or vesicular basalt with prominent horizontal and vertical jointing that erodes to a blocky talus with angular fragments up to 30 cm across. In the upper 3 m of the flow the member grades from solid basalt to a breccia of scoriaceous basalt fragments in tuff similar to, but thicker than, the basal flow breccia.

The unaltered rock is trachytic to subtrachytic intergranular aegirine-augite- to augite-olivine basalt or porphyritic basalt. Most of the olivine is altered to pseudomorphic iddingsite or antigorite and opaque minerals. The pyroxene is commonly celadonitic and much of the intergranular opaque minerals were formed through alteration of dark minerals. Plagioclase is commonly altered to zeolites. Weathered surfaces are red-brown with hematite.

Source of most basalt flows in member 1 is uncertain. Basalt dikes in the map area are thin and sparsely distributed, although feeder dikes may be buried under subsequent flows. A gabbro intrusion in Rancherias Dome was probably the source of a thick

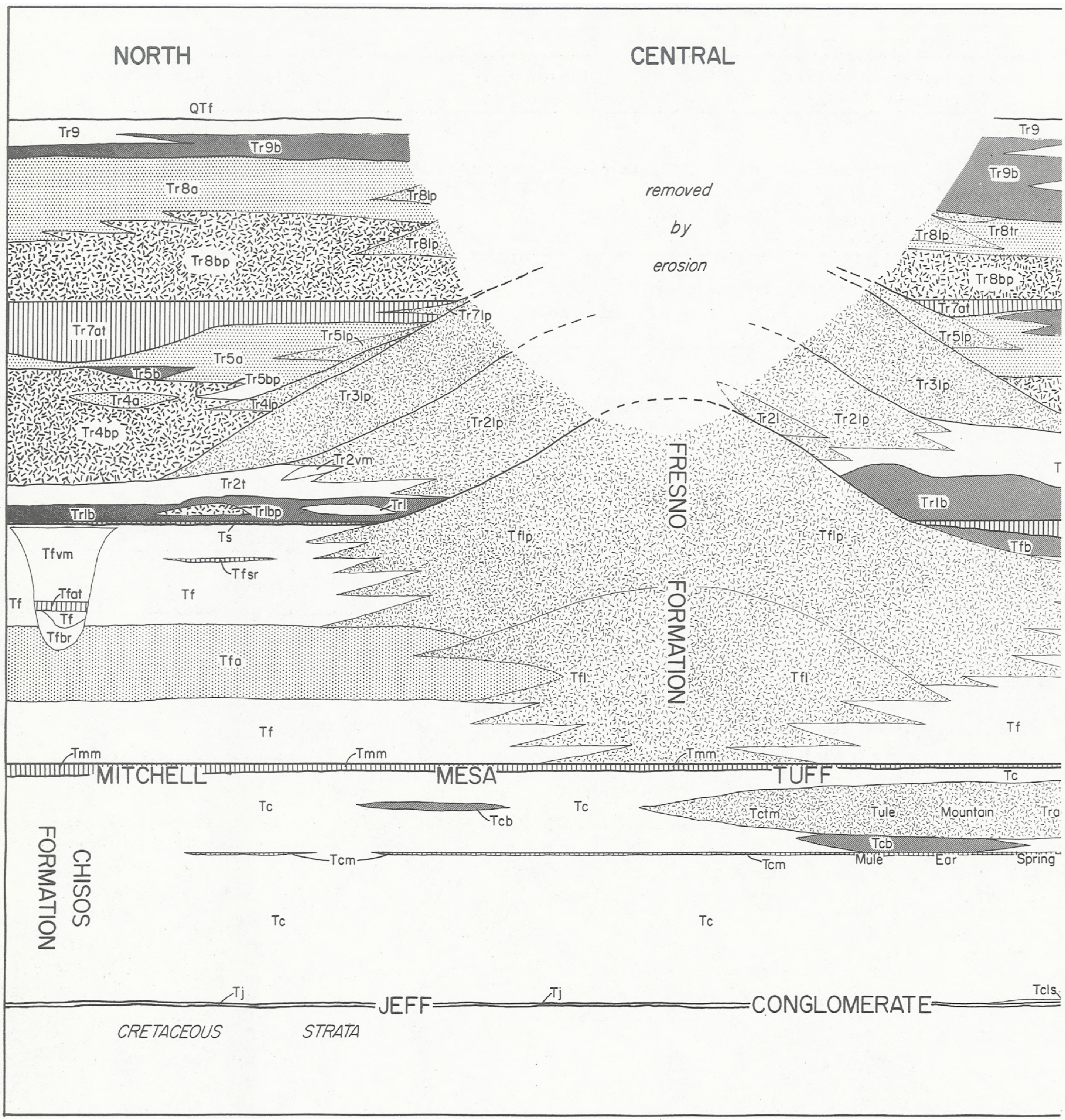
TABLE 5

Correlation of Mapped Subdivisions of the Rawls Formation (Modified and extended from Dietrich 1965:130 by McKnight 1968:79-80)

Bofecillos Mountains Area (McKnight 1968)	Presidio Area (Dietrich 1965)	Tascotal Mesa Quadrangle (Erickson 1953)
Member 9 Tr9, conglomerate with minor sandstone and tuff overlying and interbedded with flows of basalt (Tr9b)	Upper Member Tr, sedimentary rock overlying and interbedded with porphyritic basalt (Tr9)	Not mapped separately, occurs as thin layers between flows
*Tr9b, basalt	Tr9, porphyritic basalt	Trb, basalt
Tr9f, bolson fill interbedded with flows of basalt Tr9b and conglomerate Tr9	Not present	Not present
Member 8 Tr8tr, trachyte	Middle Member Not present	Not present
Not present	Tr8p trachyandesite porphyry overlying trachyandesite, Tr8	Included in trachybasalt porphyry, Trbp
*Tr8a, trachyandesite	Tr8, trachyandesite	Tra, trachyandesite
Not present	One outcrop, included in trachybasalt porphyry, Tr4	Trb, basalt
*Tr8bp, trachybasalt porphyry	Tr4, trachybasalt porphyry	One thin flow, included in basalt, Trb
Tr8lp, latite porphyry between flows of Tr8a or Tr8bp	Not present	Not present
Member 7 *Tr7at, partly welded ash-flow tuff	Lower Member Tr7, mafic ash-flow tuff	Trvb, volcanic breccia
Tr7lp, latite porphyry between ash-flows of Tr7at	Not present	Not present
Member 6 Not present	Tr6, trachyte	Not present
Member 5 *Tr5a, trachyandesite	Tr5, trachyandesite	Not present
Tr5bp, trachybasalt porphyry between flows of Tr5a	Not present	Trbp, upper part
Tr5lp, latite porphyry between flows of Tr5a or between Tr5a and Tr7at	Not present	Not present
Tr5b, basalt above Tr4bp and below Tr5a	Not present	Trb, basalt

Bofecillos Mountains Area (McKnight 1968)	Presidio Area (Dietrich 1965)	Tascotal Mesa Quadrangle (Erickson 1953)
Member 4 *Tr5bp, trachybasalt porphyry	Tr4, trachybasalt porphyry	Trbp, trachybasalt porphyry
Tr4a, trachyandesite between flows of Tr4bp	Not present	Thin flows, included in trachybasalt porphyry, Trbp
Member 3 *Tr3lp, latite porphyry and interbedded sedimentary rock	Tr3, trachyandesite	Included in Trbp
Member 2 *Tr2t, tuff and interbedded sedimentary rock	Tr2, rhyolitic ashflow tuff	Included in Tascotal Formation
Tr2lp, latite porphyry interbedded with Tr2t	Not present	Not present
Tr2l, latite between flows of Tr2lp	Not present	Not present
Tr2vm, volcanic mudflows between flows of Tr2lp	Not present	Not present
Member 1 *Trlb, basalt and interbedded sedimentary rock	Trl, Trla basalt	Not present
Trl, large exposures of sedimentary rock and tuff not included in Trlb	Included in Trl and Trla	Not present
Trlbp, trachybasalt porphyry between flows of Trlb	Not present	Not present

*Indicates index rock types for each member.


NORTH
CENTRAL
QTf
Tr9
Tr9b
Tr8a
Tr8lp
Tr8bp
Tr8tr
removed
by
erosion
Tr7at
Tr7lp
Tr5lp
Tr5a
Tr5b
Tr5bp
Tr4a
Tr4lp
Tr3lp
Tr4bp
Tr2lp
Tr2l
Tr2vm
Tr2t
Trlb
Trlbp
Trl
Tfb
Ts
Tfvm
Tflp
Tfsr
Tf
Tfat
Tfbr
Tfa
Tfl
FRESNO FORMATION
Tmm
MITCHELL MESA TUFF
Tc
Tcb
Tctm
Tule Mountain
Tcm
Mule Ear Spring
CHISOS FORMATION
Tj
JEFF CONGLOMERATE
Tcls
CRETACEOUS STRATA

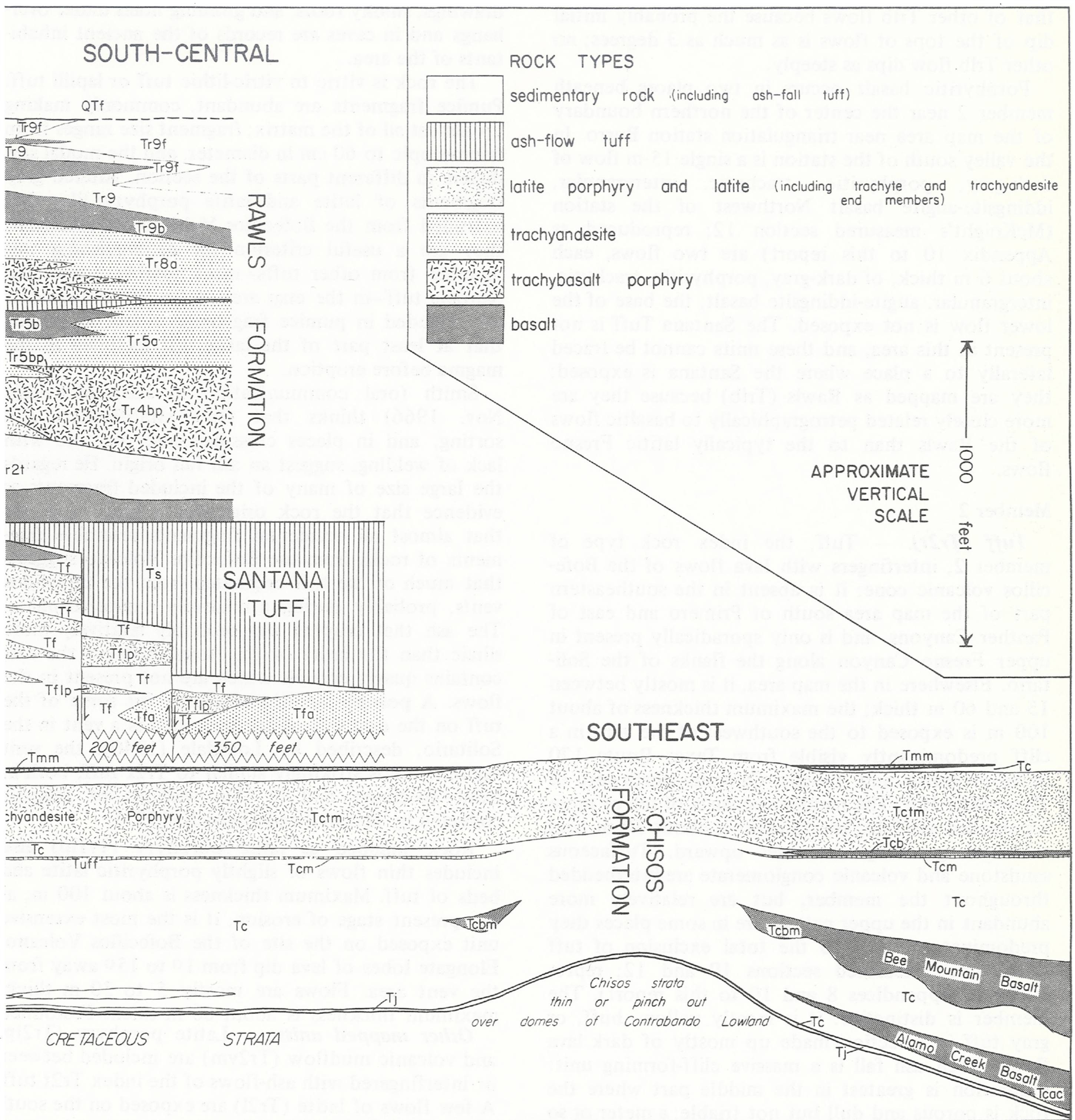


FIGURE 14

Tertiary strata mapped in the Bofecillos Mountains area.

(From McKnight 1968: Fig. 14)

wedge-like succession of basalt flows in Rawls member 1 to the east. Petrographically the basalt in this area resembles that elsewhere, but the rock is generally more vesicular and weathers gray rather than brown. The lava was probably more viscous than that of other Trlb flows because the probably initial dip of the tops of flows is as much as 3 degrees; no other Trlb flow dips as steeply.

Porphyritic basalt occurs in two places beneath member 2 near the center of the northern boundary of the map area near triangulation station Burro. In the valley south of the station is a single 15-m flow of dark-gray, porphyritic, trachytic, intergranular, iddingsite-augite basalt Northwest of the station (McKnight's measured section 12; reproduced as Appendix 10 to this report) are two flows, each about 6 m thick, of dark-gray, porphyritic, trachytic, intergranular, augite-iddingsite basalt; the base of the lower flow is not exposed. The Santana Tuff is not present in this area, and these units cannot be traced laterally to a place where the Santana is exposed; they are mapped as Rawls (Trlb) because they are more closely related petrographically to basaltic flows of the Rawls than to the typically latitic Fresno flows.

Member 2

Tuff (Tr2t). – Tuff, the index rock type of member 2, interfingers with lava flows of the Bofecillos volcanic cone; it is absent in the southeastern part of the map area south of Primero and east of Panther Canyons, and is only sporadically present in upper Fresno Canyon along the flanks of the Solitario. Elsewhere in the map area, it is mostly between 15 and 60 m thick; the maximum thickness of about 100 m is exposed to the southwest of the vent in a cliff predominantly visible from Texas Route 170 between Burro and Tapado Canyons northwest of Three-Dike Hill. The member consists of ten or more superposed ash falls; the thickest is about 30 m, and thickness generally decreases upward. Tuffaceous sandstone and volcanic conglomerate are interbedded throughout the member, but are relatively more abundant in the upper part where in some places they predominate, almost to the total exclusion of tuff (McKnight's measured sections 10 and 12; reproduced in Appendices 8 and 10 to this report). The member is distinctive: it is mostly yellow, buff, or gray tuff in a section made up mostly of dark lava flows. Each ash fall is a massive cliff-forming unit: induration is greatest in the middle part where the rock is porous and dull but not friable; a meter or so of rock at the base and a thicker zone at the top, comprising up to half the ash fall, are distinctly softer and slightly to moderately friable. Erosion accentuates these variations: in places the base is undermined and the upper part slopes gently back from nearly vertical cliffs of the middle part; elaborate erosional forms, including lensoidal caves up to 2 m high and 3 m across, are common in the upper part. Cave drawings, smoky roofs, and grinding holes under overhangs and in caves are records of the ancient inhabitants of the area.

The rock is vitric to vitric-lithic tuff or lapilli tuff. Pumice fragments are abundant, commonly making up almost all of the matrix; fragment size ranges from microscopic to 60 cm in diameter, and the modal size differs in different parts of the section. Altered gray fragments of latite and latite porphyry like that extruded from the Bofecillos Volcano are abundant; they are a useful criterion for distinguishing this member from other tuffs–most notably nonwelded Santana tuff–in the map area. A few latite fragments are included in pumice fragments, a fact suggesting that at least part of the latite was included in the magma before eruption.

Smith (oral communication to John McKnight Nov. 1966) thinks that faint stratification and sorting, and in places cross-bedding, together with lack of welding, suggest an ash fall origin. He regards the large size of many of the included fragments as evidence that the rock originated nearby. The fact that almost all accidental fragments resemble fragments of rocks from the Bofecillos Volcano suggests that much of the tuff originated from the Bofecillos vents, probably during a relatively explosive phase. The ash that erupted was probably relatively more silicic than the latite or the flows, because the tuff contains quartz crystals which are not present in the flows. A possible additional source for some of the tuff on the east side of the map area is a vent in the Solitario, described by Lonsdale (1940); the vent agglomerate is strikingly similar to Tr2t tuff, both in hand specimen and in thin sections of samples collected by Maxwell and Dietrich (1971).

Rock mapped as latite porphyry (Tr1lp) also includes thin flows of slightly porphyritic latite and beds of tuff. Maximum thickness is about 100 m; at the present stage of erosion, it is the most extensive unit exposed on the site of the Bofecillos Volcano. Elongate lobes of lava dip from 1° to 15° away from the vent area. Flows are mostly 5 to 30 m thick; maximum thickness is about 60 m thick. Festooned

Other mapped units. – Latite porphyry (Tr2lp) and volcanic mudflow (Tr2vm) are included between or interfingered with ash-flows of the index Tr2t tuff. A few flows of latite (Tr2l) are exposed on the south and east sides of the vent; maximum thickness is about 30 m. The rock is similar in outcrop and petrography to latite of the Fresno (Tfl).

flow structure is well developed on many flows and is accentuated by differential erosion of nonresistant zones between pressure ridges; festoons are convex away from the source vent of the Bofecillos Volcano. The rock looks essentially the same, both in outcrop and under the petrographic mircoscope, as the latite porphyry of the Fresno Formation (Tflp).

A rock unit interpreted as several volcanic mudflows (Tr2vm) crops out between flows on the north side of the Bofecillos cone. Maximum thickness is about 15 m; it is mostly massive breccia of gray to white latite porphyry and latite fragments in a gray to green celadonitic tuffaceous matrix with interbeds of volcanic conglomerate and tuffaceous sandstone. It is in all respects similar to laharic breccias described by Fisher (1960).

Member 3, latite porphyry (Tr3lp)

Member 3 (Tr3lp) consists predominantly of latite porphyry, but contains some porphyritic latite. It is made up of essentially the same type of lava flows as Tr2lp and Tr1lp; it is distinguished from Tr2lp because it overlies, rather than interfingers with the index tuff (Tr2t) of member 2.

Member 3 has been stripped away from the high-standing central part of the Bofecillos Volcano, but it is exposed in an interrupted ring around the cone. Maximum thickness, south of the vent in the upper part of Tapado Canyon, is about 100 m.

Member 4

Trachybasalt porphyry (Tr4bp). – The index rock type of member 4 is a distinctive trachybasalt porphyry that contains up to 40% tabular plagioclase phenocrysts as much as 6 cm long; even the largest crystals are only a few millimeters thick. In a few of the upper flows the crystals have rounded rhombic outlines (see member 8–Tr8bp, for discussion). On slightly weathered surfaces the white- to gray-weathering feldspar phenocrysts are conspicuous in a red-brown, gray or black groundmass sparsely speckled with red-brown grains of iddingsite.

The trachybasalt porphyry forms a discontinuous ring around the Bofecillos eruptive center. Dietrich (1965) estimated that it is about 200 m thick north of the map area. It thins southward against latite porphyry (Tr3lp) flows on the flanks of the Bofecillos Volcano–the cone was partly, but not totally, inundated. East of the volcano, the maximum thickness is only about 60 m, probably because of uplift of the Solitario before or during extrusion. Maximum thickness to the west is about 130 m, and to the south, about 100 m; it is thinner across the Rio Grande in Mexico.

The trachybasalt porphyry spread as flows ranging from a meter to about 15 m thick; some of the thinner flows are probably flow-units of a larger flow, as was described in the Bee Mountain Basalt. A nonresistant and commonly crumbly basal flow breccia, a few inches to several feet thick consists of pebble- to boulder-size scoriaceous blocks of altered trachybasalt porphyry weathering red-brown; calcite, chalcedony, and celadonite partly or totally fill fractures and vesicles. Above the flow breccia, the rock is vesicular and amygdaloidal, subophitic to intergranular or intersertal, titaniferous or aegiritic augite-iddingsite trachybasalt porphyry that weathers red-brown. Fresh hand-specimens are difficult to collect because alteration to celadonite and zeolites is common throughout the flow. The alteration, and the resultant susceptibility to weathering and erosion generally increase with the percentage of vesicles. The middle part of the flow is the most resistant to erosion; it stands as a steep but rounded and generally scalable cliff. The upper part is highly scoriaceous and weathers red-brown; the top few feet is a clinker-like rubble of boulder- to sand-size fragments that commonly grades into the basal flow breccia of the next higher flow.

Dietrich (1965:127-128) described the major source of the trachybasalt porphyry:

> A group of dikes exposed in and near the domes in southeastern Presidio Area is the probable source of trachybasalt porphyry lava member (Tr4) of Rawls Formation. The dikes, commonly 20 to 50 feet thick, cut "Fresno Formation," ash-flow tuff (Tr2), trachyandesite (Tr3), and the lower flows of trachybasalt porphyry in and around the small domes. The greatest thickness of trachybasalt porphyry accumulated in the vicinity of these dikes; in that area, interbedded sedimentary rock is rare.

Thin dikes and relatively small intrusions of trachybasalt porphyry in the central part of the Bofecillos Mountains Area were probably also a source of some of the flows.

Other mapped units. – Mapped units included between or interfingered with the flows of trachybasalt porphyry (Tr4bp) are flows of trachyandesite (Tr4a), similar to Tr5a (next section), and latite porphyry (Tr4lp), similar to that described in the Fresno (Tflp) and lower members of the Rawls Formation (Tr2lp, Tr3lp).

Member 5

Rawls member 5 is indexed by a pulse of trachyandesite extrusion that began before cessation of trachybasalt porphyry extrusion characteristic of member 4. The resultant interlayering and interfingering of the two rock types makes the contact between the two members more or less arbitrary; the contact was placed beneath the lowest trachyandesite flow that could be traced laterally to a part of the section consisting dominantly of trachyandesite (Fig. 14).

Trachyandesite (Tr5a). – The trachyandesite of member 5 spread as flows a few feet to about 15 m thick. Above a basal flow breccia, mostly less than 30 cm thick, the rock is brown- to olive-green-weathering, nonvesicular, gray trachyandesite, commonly with yellow-brown to gray-green celadonite or zeolite(?) mottling. In contrast to a scoriaceous upper surface common in lower flows, the top of the member 5 trachyandesite flows is mostly slightly vesicular. The flow tops may be festooned with pressure ridges several feet apart.

The rock is of essentially the same mineral composition as trachyandesite (Tfa) of the Fresno Formation. Some of the member 5 trachyandesite is, in fact, petrographically indistinguishable from it, but most has a pronounced trachytic texture, accentuated by plagioclase crystals 5 to 10 times longer than wide.

The member 5 flows were probably fed by trachyandesite dikes, which are common in the Bofecillos Mountains; an irregular intrusion of trachyandesite Tia on the west side of the eruptive center, about one mile south of triangulation station Burro, feeds Tr4a and Tr5a flows.

Other mapped units. – In addition to the index trachyandesite (Tr5a), mapped units in member 5 include trachybasalt porphyry (Tr5bp), latite porphyry (Tr5lp), and basalt (Tr5b). Trachybasalt porphyry (Tr5bp) and latite porphyry (Tr5lp) are similar to rocks lower in the section, and probably have the same source areas.

Basalt (Tr5b) is exposed at two widely-separated localities. The rock at a 30-m sequence of five or more basalt flows southwest of the central vent of the Bofecillos Volcano between Rancherias Dome and Panther Dome is like the vesicular gray-weathering variety of basalt in member 1 in the same general area, and probably also originated from the gabbro intrusion in Rancherias Dome. Northeast of the Bofecillos Volcano, in a mesa north of the present road out of Fresno Canyon, several flows of basalt (Tr5b) and interbedded tuff totalling about 30 m rest on trachyandesite flows (Tr5a) and are overlain by ash-flow tuff (Tr7at). These flows, assigned to member 5 on the basis of stratigraphic position, are a southward extension of a sequence of basalt (Trb) flows that Erickson (1953) mapped and described.

Member 7

Ash-flow tuff (Tr7at). – Exposures of ash-flow tuff (Tr7at) are erosional remnants of a sheet that extended from southeastern Presidio Area (Dietrich 1965) and southern Tascotal Mesa Quadrangle (Erickson 1953) through all but the western part of the Bofecillos Mountains Area and an undetermined distance into Mexico. It is as much as 62 m thick in McKnight's measured section 12 (Appendix 10), near the north boundary of the map area; it thins southward and is discontinuous in most of the area, probably because of relief of the surface over which it spread. It did not cover the Bofecillos Volcano.

The rock is nonwelded to thoroughly welded, crystal-vitric to lithic-vitric tuff. Anorthoclase phenocrysts (5 to 20%) and abundant accidental fragments of latite and latite porphyry (3 to 10%) like that in flows from the Bofecillos Volcano are characteristic of the member.

The member is mostly a simple cooling unit 5 to 30 m thick consisting of one or several ash flows. A few feet of bright orange or pink, friable, nonresistant, palagonitic, nonwelded tuff at the base grades upward in a few inches to brownish-gray, slightly friable, nonwelded tuff that forms the lower part of a near-vertical cliff overhanging the nonresistant tuff below; the brownish-gray colored rock here and higher in the section is probably characteristic of the zone of vapor-phase crystallization (Smith 1960). A few feet higher in the cliff the rock grades to well-indurated, brownish-gray rock that is slightly to intensely eutaxitic; there is no vitrophyre. The welding and attendant foliation die out upward in the cliff. The upper part of the unit is slope-forming, light-brownish-gray, friable, nonwelded tuff that may be a few feet thick or comprise the entire upper half of the cooling unit. Where the unit is nonwelded it commonly grades through similar zones except that the eutaxitic zone is absent.

The cooling unit is compound in many places, probably, as Smith (1960:801) stated, "... because the intervals between ash flows were too great for readjustment to a single-unit cooling gradient." The compound unit has alternating gradational zones of welded tuff, nonwelded but indurated brownish-gray tuff, and friable orange or pink palagonitic tuff described in simple cooling units. These zones may be parts of ash flows or include several ash flows; distinctly separate zones may grade laterally in a few hundred feet into a single zone (McKnight's measured section 11; reproduced as Appendix 9 to this report).

Latite porphyry (Tr7lp). – In a few places flows of latite porphyry (Tr7lp) from the Bofecillos Volcano are interbedded with ash flows of the index tuff (Tr7at). The rock resembles the latite porphyry elsewhere in the Rawls and Fresno Formations.

Member 8

Trachybasalt porphyry (Tr8bp). – The lower part of member 8 consists of trachybasalt porphyry

(Tr8bp) in flows that are as much as 15 m thick. It is discontinuously exposed in high mesas in a 5-km-wide belt extending three-quarters of the way around the Bofecillos Volcano from an eastward pinchout in Panther Dome to the south, clockwise through the Presidio Area (Dietrich 1965) and Tascotal Mesa Quadrangle (Erickson 1953) to the north, and on to a pinchout south of Arroyo Segundo to the east; it is absent and probably was not deposited southeast of the Bofecillos Volcano from triangulation station Madril.

The lower flows are a continuation of the extrusive pulse that began with member 4 (Tr4bp), but they grade upward to flows with somewhat different outcrop form and lithology. The upper flows form steeper cliffs and are thicker than the lower flows, probably because they moved mostly as a single unit, rather than as a number of flow-units. Intense deuteric or post magmatic alteration, common throughout lower flows, is present only near the base and top of the upper flows. The fresh groundmass of the upper flows is gray, rather than black, and the rock weathers pale-gray rather than red-brown. Dull, not glassy, white plagioclase phenocrysts are mostly oligoclase-andesize, rather than andesine-labradorite. They are embayed and thoroughly vacuolized; rounded corners are probably caused by partial resorption. Some have alkali feldspar rims formed either by replacement or by antirapikivi overgrowth; shapes tend to be rhombic rather than rectangular. The rock contains a lower percentage of dark minerals, and intergranular hornblende is relatively more abundant than aegiritic augite. Some of the rock is actually mafic trachyandesite porphyry, but it is all mapped as trachybasalt porphyry because the trachyandesite is interbedded with, gradational from, and probably genetically related to trachybasalt porphyry.

An extreme felsic end product of the above gradation is found east of the Bofecillos Volcano at the southeast end of the mesa east of Llano Dome and west of Fresno Canyon, where a zone at the top of a mafic trachyandesite porphyry flow was probably hydrothermally altered by fluids escaping from the lower part of the flow. Rhombic plagioclase phenocrysts are completely converted to alkali feldspar—mostly anorthoclase—and much of the interstitial material between plagioclase laths was altered to prismatic sodic pyroxene(?), alkali feldspar, fibrous zeolites, and chalcedony. Aegiritic augite grains are parly altered to a yellow unidentified amphibole or brittle mica that may be stilpnomelane, astrophyllite, or lamprophyllite.

Trachyandesite (Tr8a). — The upper part of member 8 is trachyandesite similar to that of member 5. It was present in a ring around the Bofecillos Volcano, except possibly to the east; it has been extensively removed by erosion and is preserved only as the caprock on isolated mesas. Maximum thickness in the map area is about 30 m.

Festoon structure is common in the thicker flows. Laminae between pressure ridges are nearly vertical at the original surface of the flow, but curve downward away from the direction of movement; some dip as little as 45° where they die out 3 to 6 m below the surface. Below the laminae associated with pressure ridges, a foot or more of nonstructured or irregularly structured rock is commonly underlain by rock with horizontal laminae that is present almost to the base of the flow. Erosion along pressure ridges and weathered flow laminae at the top of some of the flows emphasizes the festoon structure to such an extent that it is easily visible on aerial photographs.

Dietrich (1965) located a probable major vent of member 8 trachyandesite eruption in the east-central part of Presidio Area. An additional source might be some of the many trachyandesite dikes on the Bofecillos Volcano, some of which may have extended as high as member 8 before the volcano was dissected.

Other mapped units. — Latite porphyry (Tr8lp) is interlayered with the two index rock types; it is similar to latite-porphyry units lower in the section. About 15 m of gray sodic trachyte porphyry (Tr8tr) crops out above member 8 trachyandesite in a high-standing mesa northwest of Tapado Dome; it contains sanidine and aegirine phenocrysts in a groundmass of trachytic alkali feldspar with interstitial hematitic riebeckite. Thin beds of sedimentary rock and tuff between flows were not mapped.

Member 9

In contrast to earlier Rawls flows, many of the basalt flows of member 9 (Tr9b) were extruded after appreciable faulting; as a consequence, they are interbedded with thick sequences of graben-filling sedimentary rock (Tr9). Northeast of Panther Dome, member 9 is more than 100 m thick and consists dominantly of sedimentary rock; it may be thicker near Redford where the base is not exposed.

Basalt (Tr9b). — The index basalt of member 9 is conformably exposed above trachyandesite of member 8, capping mesas west and southwest of the Bofecillos Volcano, and capping Rincon Mountain to the east. Individual basalt flows are mostly less than 15 m thick; at least 4 superposed flows occur in the map area and Dietrich (1965) reported at least 10 in the Presidio Area. Typically a 30-to-100-cm-thick, red-brown, porcelaneous, baked zone beneath the flow is overlain by a slightly vesicular basal flow breccia mostly less than 60 cm thick; above the breccia is horizontally-laminated nonvesicular basalt that makes up most of the unit. The upper 1 to 3 m may have steeply inclined laminae associated with festooned pressure ridges on the top of the flow; vesiculation in this zone is slight. In a few places, particularly in the upper part of the Madera Canyon, the basalt has scoriaceous and tuffaceous breccias at the base and top, and is indistinguishable, except by stratigraphic position, from basalt of member 1.

Except for generally lower percentages of plagioclase (0-5) and augite (0-3) phenocrysts, and a tendency toward fresher, less iddingsitic olivine, the rock is petrographically similar to the index basalt of member 1. Faint spherical white splotches 2 to 5 mm in diameter are common in member 9 basalt but were not found in lower members; they are strikingly accentuated on weathered surfaces. The origin is unknown, but is perhaps related to alteration or devitrification of groundmass constituents that progressed outward from widely-separated centers.

Sedimentary rock (Tr9). – Poorly-sorted massive gray to white conglomerate and conglomeratic sandstone of member 9 (Tr9) partly fill the Redford Bolson, the Santana Bolson, and other grabens in the fault-block zone; more than 60 m accumulated at several places.

The unit is well exposed at the southeast end of the Redford Bolson about 200 m north of Texas Route 170, 3 km west of the bridge across Tapado Creek, where it rests disconformably on trachybasalt porphyry of member 4 (Tr4bp). It is about 20 m thick with the lower 6 m covered; the upper 15 m forms a rounded bluff with cavernous weathering. The rock grades from poorly sorted, massive, sandy volcanic conglomerate in layers 2 to 6 m thick to faintly-bedded conglomeratic sandstone in layers 30 cm to 2 m. Rounded and subrounded clasts in the conglomerate average about 3 cm but range up to 25 cm in diameter; they include abundant trachyandesite, latite porphyry, and trachybasalt porphyry from the Rawls and Fresno Formations, and a few pebbles are the distinctive ash-flow tuff or Rawls member 7 (Tr7at). The matrix is pale-buff to gray, moderately-indurated, calcite-cemented volcanic arenite with weathered grains of feldspar and volcanic rock, and sparse fresh grains of quartz and opaque minerals.

In general, except for a few localities (see following five paragraphs) and except for induration, the composition and lithology of the graben-filling Tr9 conglomerate is nearly the same as the modern side stream alluvium (Qals) and the pediment gravels (Qg1-4) in the same area–a fact suggesting a similar source for the Tr9 conglomerate in the Bofecillos Mountains. The conglomerate was probably deposited mostly as alluvial fans.

Gray conglomerate, with rock fragments atypical of those elsewhere in Rawls member 9, is exposed in the western part of the map area along the north boundary where a graded dirt road parallels Palo Amarillo Creek. Adjacent to the north in the Presidio Area, Dietrich (1965) mapped this exposure as northeast side of the Redford Bolson about 100 m south of the northern map boundary. The unit is orange-weathering, porcelaneous, devitrified, zeolitic, crystal-vitric tuff with about 3% gray accidental fragments up to 5 cm in diameter in a pink matrix; it is uniform from base to top. It is probably not correlative with ash-flow tuff (Tr9t) mapped by Dietrich (1965).

Interbedded conglomerate and bolson fill (Tr9f). – In the Santana Bolson, typical "gray" Tr9 conglomerate is intercalated with "pink" conglomeratic sandstone typical of bolson fill (QTf) in alternating beds or groups of beds as much as 50 ft thick; this interfingered sequence is arbitrarily mapped as bolson fill in the Rawls Formation (Tr9f).

APPENDIX 2

TERTIARY INTRUSIONS

(modified from McKnight 1968:104-111, 119-126)

INTRUSIVE ROCKS

Dikes and Sills

Dikes are abundant in and around the Bofecillos Volcano but are progressively less common away from the vent; only the larger ones are mapped. They are aligned radially around the volcano, and are particularly abundant along the northwest trend followed by late-volcanic and post-volcanic block faults. Exposed sills are distinctly less numerous, probably because the well layered Cretaceous strata favorable for concordant emplacement crop out only along the edges of the map area. Contact effects extend at most a few feet on either side of the dike or sill; normally iron-oxide staining is the only noticeable difference in flows intruded by dikes, but tuff is commonly baked to red-brown, slightly porcelaneous rock that is more resistant to erosion than the unaltered tuff.

Dikes and sills of latite porphyry, trachyandesite, trachybasalt porphyry, and basalt are similar in composition to flows of the same rock type in the Fresno and Rawls formations. Most of the intrusive rock, however, is more intensely altered: intergranular pyroxene is saccharoidal or completely transformed to celadonite; plagioclase phenocrysts are more corroded, embayed, vacuolized, and partly altered to zeolites or clay minerals; olivine is altered to iddingsite, antigorite and opaque minerals. By far the most abundant dike rock in the area is latite porphyry (Tilp); some dikes are as much as 6 m thick and some are several kilometers long. Trachyandesite (Tia) is next most common in dikes ranging up to 6 m thick and a few thousand meters long. Generally sparse latite (Til), basalt (Tib), and trachybasalt porphyry (Tibp) dikes are as much as 2 m thick and traceable for 300 m or less; trachybasalt porphyry dikes are most abundant in the general area of the Bofecillos vent and south of a large irregular trachybasalt porphyry pluton in Burro Canyon, but they are found throughout the map area. A few dikes in the map area are composed of light-gray to gray-green, trachytic, intergranular, hornblende sodic trachyte porphyry (Titr) consisting of glassy, partly-corroded phenocrysts of sanidine or anorthoclase and aegirine-augite in a groundmass of alkali feldspar with green interstitial sodic hornblende and disseminated opaque minerals; alteration of pyroxene and amphibole to vermicular celadonite is common. Rhyolite (Tir) dikes and sills crop out in the eastern part of the map area. The rock is mostly altered with a porous chalky white matrix with iron oxides in fractures and in liesegang bands; sparse phenocrysts of glassy to dull feldspar and glassy quartz are a few millimeters long.

Laccoliths

Laccoliths are mostly intruded into the flaggy Boquillas Formation, but they are also emplaced beneath some of the thicker lava flows and probably also in strata beneath the Boquillas. Several are dated relative to volcanism by nearly horizontal volcanic strata which overlap the partly deroofed intrusive domes.

The form of intrusions in the Contrabando Lowland is typical of that elsewhere in the map area. The lowland is a compound dome bowed up by clustered laccoliths and sills that intrude flaggy Boquillas limestone; the intrusive rock is mapped as diorite and gabbro (Tidg). Similar concordant bodies probably exist at depth because the intrusions themselves are commonly domes; eight holes drilled in Contrabando Dome in search of mercury deposits under the supervision of L. C. Whitaker (oral communication to John McKnight January 1964) penetrated several layers of igneous rock similar to that at the surface. The exposed bodies are in all stages of dissection, and arroyos incised through the intrusions provide excellent cross-sections exhibiting a diversity of forms and contact effects. Bases are generally not faulted, but they may arch or sag; tops may be symmetrical or asymmetrical and the arching may be uniform or the sides steep and the crown relatively flat. The roof is commonly faulted and dikes or intrusive wedges commonly extend upward into the overlying limestone; at least one body is a trapdoor laccolith. Limestone is baked gray, recrystallized, and partly silicified a few feet to several tens of feet from the contact.

Probably the largest exposed intrusion of the Contrabando Lowland is the Wax Factory Laccolith, a syenodiorite intrusion named and described by Lonsdale (1940). It is as much as 50 m thick and at least 6 km across. Smaller laccoliths to the southwest consist of medium- to fine-grained rock that is black to gray where fresh, but altered to olive-green or white in most places. Fractures are occupied by hematite-limonite. To the unaided eye, the rock is similar to that of the Wax Factory Laccolith, but three thin-sectioned samples are celadonitic augite syenodiorite; olivine-titanaugite analcitic syendiorite; celadonitic syenogabbro.

Irregular Intrusions

Riebeckite rhyolite intrusions. – Two riebeckite rhyolite plutons, each about 600 m across, are exposed in the northern part of the area. A generally discordant body north of the old road out of Fresno Canyon, crosscuts the upper part of the Fresno Formation and the Rawls Formation through member 5 on the northeast and northwest; faults truncate it on the southeast and southwest. The base is not exposed. A 60-m section is exposed on the southwest side. Contact alteration is slight where it intrudes lava flows; Fresno tuff is porcelaneous and red-brown in a contact zone a few feet thick. The metamorphosed zone forms a low-lying cuesta between less resistant tuff and the intrusive rhyolite. The rhyolite is mostly altered to a rubble of white or gray silt- to pebble-size chalky or porcelaneous grains. About 10% of the intrusion is fresh rock which occurs as rounded blocks some more than a meter across, in a matrix of the rubble; many of the blocks are brecciated and contain autolithic inclusions. This fresh rock is porcelaneous and blue-gray to gray-green with corroded 1mm long anorthoclase and quartz phenocrysts; riebeckite is mostly in dendritic crystals up to 1 mm across that poikilitically include groundmass feldspar, but about 1/10 is stubby 1 mm long needles. The groundmass is strongly seriate, interlocking, anhedral alkali feldspar and quartz with interstitial celadonite.

The second riebeckite rhyolite pluton is southwest of Saucita Dome and north of the Big Bend Ranch road. It was intruded essentially concordantly between latite porphyry flows of Rawls members 2 and 3, and is at most 15 m thick; the intrusion was probably laccolithic in form, but all of the roof except part of a nearly flat-lying lava flow on the crown is eroded away. The rock is brown-weathering, cream or yellow, and intergranular, with flow structure accentuated in outcrop by dark riebeckite needles as much as 2 mm long, and by brown splotches several millimeters long of hematite that is pseudomorphic after dendritic-poikilitic riebeckite. The groundmass is strongly seriate, trachytic alkali feldspar with interstitial quartz and celadonite.

Bogles Domes. – Triangulation station Bogles, in the northeastern part of the map area, is approximately at the center of a roughly circular area a little over 2 km across that contains overlapping intrusions of latite emplaced into the middle and upper part of the Fresno Formation and as high as the lower trachybasalt porphyry flows of Rawls member 4. The intrusions are generally domical but several are irregular where they abut against, or were emplaced along, the steep sides of previously intruded domes; near the edges of the area of intrusion they are mostly concordant. This compound mass was emplaced near the surface and is perhaps extrusive in part; non-domed volcanic mudflows of the valley-fill sequence of the Fresno Formation (Tfvm) lap onto it from the northeast side and most of the mudflows contain blocks similar to rock of the Bogles intrusions. Beds and flows of Rawls members 1 and 4 also lap onto some of the domes, but elsewhere they are themselves tilted–a fact indicating that emplacement continued through extrusion of these units; the upper trachybasalt porphyry flows of member 4 buried the partly eroded complex, and were not subsequently arched (Fig. 15). The rock is blue-gray to white, flow laminated, intergranular aegiritic augite-hornblende latite with sparse biotite flakes 2 to 4 mm across.

Big Hill intrusion. – At the southeast end of Santana Mesa at the Big Hill of Texas Route 170, a faulted dome-shaped slightly discordant body of rhyolite porphyry (Tirp) at least 1900 m across and about 250 m thick is partly included within and partly immediately beneath Santana Tuff. It extends across the river into Mexico. The contact with the flanking Santana Tuff is poorly exposed or inaccessible, but as nearly as can be determined the Santana, although distinctly upwarped, abuts into the intrusion with low angle discordance. Thus, for unknown reasons, the intrusion probably diverges somewhat from a true laccolith. While joints in the rock are mostly irregular, some in the upper part parallel the upper contact. Although these are probably partings paralleling flow laminae, no flow structure is visible.

The groundmass is red-brown; about 50% of the rock is phenocrysts of cloudy white feldspar and clear quartz as much as 1 cm long. Two samples collected by Maxwell and Dietrich (1971) contain abundant corroded fractured and embayed sanidine and quartz, and a few percent of albite-oligoclase; sparse grains of celadonitic augite, opaque minerals and opaque-mineral-rimmed basaltic hornblende are mostly less than 2 mm long. The groundmass is hematite-dusted devitrified glass containing vermicular celadonite(?), disseminated opaque minerals, and clay minerals or zeolites. With nicols crossed, the groundmass commonly exhibits patchy extinction, which is the "snowflake" texture described by Snyder (1962) as poikilitic quartz inclosing minute feldspar grains; Anderson (1962) interpreted the "snowflakes" as a texture resulting from devitrification and subsequent

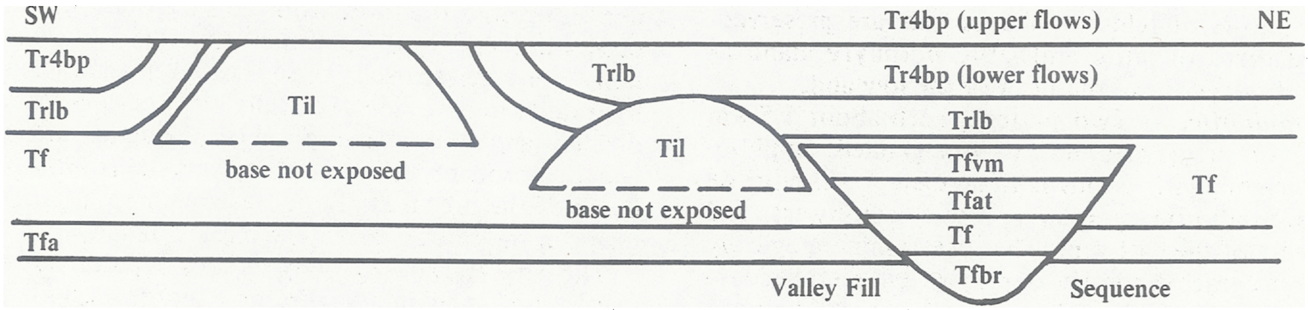


FIGURE 15

Diagramatic cross-section through Bogles Domes. Volcanic mud-flow of the Fresno valley-fill sequence (Tfvm) contains fragments of latite from Bogles Domes. Arched Rawls basalt (Trlb) and trachybasalt porphyry (Tr4bp, lower flows) indicate that some of the domes were intruded after others were dissected. (Modified from McKnight 196: Fig. 12)

recrystallization. Faint microscopic foliation is visible in the matrix of one of the samples.

Intrusions of Rancherias Dome. – Rancherias Dome is eroded to an elliptical valley about 1.5 km long with gently outward-dipping upper Fresno and Rawls flows forming a discontinuous in-facing cuesta. The flows rest unconformably on undifferentiated Comanche, Pen, Boquillas or Jeff strata which floor the valley. The Chisos, Mitchell Mesa, and the lower part of the Fresno Formation–totaling more than 250 m elsewhere–are absent, either by nondeposition or erosion; from available exposures, it is impossible to state whether the uplift took place before, during, or after their accumulation. The uplift is probably intrusive because the axial area is cut by numerous dikes and irregular plutons, including a discordant gabbro (Tig) intrusion about 600 m across at the west end. Abundant white colloform hydrothermal chalcedonic silica occurs in fissure veins as much as 6 m thick in the gabbro, in the Pen, and between the Pen and overlying flows. Except around the gabbro intrusion, it is impossible to demonstrate outward dip of the Cretaceous and Jeff strata, because only the Pen is exposed away from the intrusion and bedding in the Pen is mostly imperceptible. If the gabbro intrusion caused the upwarping, it probably extends eastward beneath the surface about a kilometer, because the exposed gabbro is located asymmetrically on the west side of the dome. On the other hand, the fact that many of the dikes and small plutons are not gabbro suggests that the dome was formed at least in part by an unexposed intrusion.

The medium- to fine-grained subophitic pyroxene (probably titanaugite) gabbro (Tig) grades to basalt. The rock is mostly deuterically or post-magmatically altered and contains olive-green interstitial limonitic celadonite. The Comanche limestone is marbleized a few feet to several hundred feet outward from the contact; lenses of pale-green skarn–probably containing calcite, wollastonite and vesuvianite–are sporadically present in the marble. Numerous altered titanaugite-olivine basalt dikes as much as 1.5 m thick cut through the intrusion; some contain gabbro and basalt inclusions and their boundaries with the wall rock are commonly vaguely defined–these dikes may have been emplaced before the gabbro was completely solid. They may have been the source of wedge-shaped sequences of Rawls members 1 and 5 basalt flows that extend to the east and southeast of the Rancherias Dome.

Almost all of the small dikes and irregular plutons are so intensely altered that the original rock type is unknown; a few, however, are recognizable latite porphyry. Near these intrusions, particularly the more irregularly and intensely altered ones, the Pen contains abundant silt-, sand- and pebble-size fragments of the altered igneous rock; perhaps the Pen host rock behaved as a viscous fluid at the time of intrusion and incorporated and dispersed gobs of the intruding molten rock. Away from the intrusions, the Pen is typical gypsiferous clay.

Bofecillos Vents

The main source of lavas from the Bofecillos Volcano is near the center of the map area southeast of triangulation station Elephant; it consists of two vents partly surrounded by syenodiorite intrusions and by a breccia zone.

The east vent is 2 km and the west vent 1 km across; they are erosional lowlands developed on deuterically or hydrothermally altered, chalky, white, iron-oxide-stained vent rock (Tiv). Most of the vent material is poorly-indurated breccia consisting of clay-, silt-, and sand-size fragments, but blocks range up to 3 m across. In several places, the breccia grades to irregular intrusions as much as 30 m across, in which ghosts of feldspar phenocrysts are preserved. Altered dikes of latite and latite porphyry stand as resistant ridges above the floor of the lowland.

Syenodiorite. – Two plutons, each about 1.5 km across, of gray, medium- to fine-grained, hypidiomorphic-granular, aegiritic-titanaugite syenodiorite and syenodiorite porphyry flows southwest and northeast of the east vent. The rock is mineralogically similar to trachyandesite porphyry end-member lava flows of the Bofecillos Volcano and resembles glomerocrystic inclusions in the lavas. The southwestern intrusion is half-cone shaped and is discordant; the surrounding flows dip outward as much as 50°. The rock is relatively unaltered and resistant to erosion–the intrusion forms the highest peak in the map area (el. 1558 m) standing 150 m above the vent. On the other hand, at least the top of the northeast intrusion is concordant, sloping outward at about 3° beneath the flows; the base is not exposed. The intrusion is about 30 m thick where it abuts against the vent rock. The rock is moderately to intensely celadonitic; it is nonresistant and forms a valley where the overlying lava flows have been stripped away.

Breccia. – The rock mapped as breccia (Tibr) is a discontinuous shell as much as 15 m thick around the vents. It either formed as an intrusion breccia in the country rock along the contact of the vent material or it is a chilled border phase of the vent rock; it differs markedly from the breccia mapped as vent rock (Tiv) and the contact with the vent rock is sharp. It weathers red-brown; where freshly broken it is dark-green or gray-green and has a waxy luster. It is hydrothermally altered, aegirine-augite latite porphyry with faintly defined angular to rounded autolithic fragments up to a few feet across. Feldspars are mostly altered to clay minerals or zeolites. Dark minerals, except for corroded opaque phenocrysts, are altered to saccharoidal aegirine-augite; 40 to 50% of this pyroxene is common in the rock and suggests hydrothermal addition of iron and perhaps sodium.

Siliceous Fissure Veins and Replacement Deposits

Milky-white to pale-gray chalcedonic silica(s) occurs as hydrothermal deposits in several intrusive domes. It is most abundant and typically exhibited in Rancherias Dome, where steeply dipping fissure veins and lenses as much as several feet thick and a few hundred feet long cross-cut gabbro, Pen clay and Fresno tuff; a discontinuous manto occurs along the contact of the lowest lava flow and the underlying Fresno tuff or Pen claystone at the east end of the uplift.

Elsewhere in the area, the silica replaces or fills pores and fractures in country rock and was probably derived from tuff and transported by ground water. It occurs in layers or discontinuous mantos. The chalcedony contains sparsely disseminated magnetite and hydrated iron oxides. Locally it contains finely divided anhedral grains of aegirine-augite and riebeckite, probably alteration or recrystallization products of the host rock. Stylolites are common, particularly in the thicker, flat lying masses of silica.

The largest exposed body of this type of replacement silica is in middle Fresno Canyon east of the triangulation station Bogles; it is a layer several hundred feed in outcrop length and as much as 6 m thick between Fresno tuff and the underlying Boquillas Formation. The original rock type is unknown because it is completely replaced, but vaguely to well defined, angular fragments suggest that it was originally a breccia. Perhaps it was talus formed on the flanks of the Solitario before deposition of the overlying Fresno tuff.

STRUCTURES ASSOCIATED WITH INTRUSIVE DOMES

Because laccoliths are exposed in the center of several breached domes, similar partly breached domes are probably also laccolithic. Several representative laccolithic domes were discussed under the earlier heading of intrusive rock; additional data for these and other of the 11 largest domes are summarized in Table 6. Some domes in the area may be concealed by younger, as yet uneroded, strata. Abundant small unmapped faults were caused by the doming; they are mostly less than 30 m long with 1 m or less of throw and they die out upward above the doming intrusion in a few tens of feet. Only where there are marked discordances–as above the trapdoor structures of Segundo Dome and the central part of Saucita Dome–are the faults large enough to be mapped. Large faults of random orientation at the west end of Saucita Dome suggest a discordant intrusion at depth.

LLANO DOME THRUSTS AND FOLDS

Chisos, Mitchell Mesa, and Fresno Formations are intensely deformed in the east half of the Llano Dome (Fig. 16). North-trending folds and imbricate thrust faults repeat the Mitchell Mesa at least eight times. Dips are steep and some of the Mitchell Mesa slabs are overturned at 50°; bedding of most other strata, including tuff and sedimentary rock, is poorly preserved, largely because the beds were incompetent during thrusting. Similarity of these structures, though on a larger scale, to the imbricate thrusting of

EXPLANATION

Contact -- Dashed where inferred; dotted where concealed.

Fault -- U, upthrown side; D, Downthrown side; ⊢ upper plate of thrust fault; dashed where inferred; dotted where concealed.

Anticline -- Indicating plunge.

Overturned anticline -- Indicating plunge.

67 Strike and dip of beds.

85 Strike and dip of overturned beds.

S Chalcedonic silica; fills fissure-veins and replaces wall rock.

TERTIARY INTRUSIVE ROCK

ib Basalt

Ibp Trachybasalt Porphyry

TERTIARY EXTRUSIVE ROCK

Rawls Formation

4bp Member 4 -- Trachybasalt porphyry

3lp Member 3 -- Latite Porphyry

2t Member 2 -- Tuff, 2t; tuff baked by nearby intrusion, 2tb

lb Member 1 -- Basalt

Fresno Formation

fa Trachyandesite

f Tuff

fc Conglomerate

Mitchell Mesa Tuff

mm Ash-flow tuff

Chisos Formation

cb Basalt

c Tuff

cm Mule Ear Spring Tuff

FIGURE 16

Geologic sketch map of Llano Dome.
(From McKnight 1968: Fig. 15)

Mule Ear Spring in south Fresno Canyon suggests a similar mechanism of formation. Uplift of the Solitario may have caused gravity slides westward, uplift of smaller intrusive domes in the Bofecillos Volcano may have caused eastward slides, or perhaps incision of streams during volcanic activity created unstable slopes; the plane of failure was in Chisos, or lower strata—perhaps the clay-rich upper part of the Boquillas Formation. A later intrusion, perhaps along the slide plane, probably domed the contorted strata to their present position. The thrusting was not caused by the intrusive doming because domed members 2 and 4 of the Rawls formation truncate the faults. Furthermore, from the field relationships, it is unlikely that an earlier discordant intrusion caused the thrusting because: 1) practically no intrusive rock is exposed and hydrothermal effects that might be associated with such an intrusion are slight—only a few lenses of chalcedonic silica, 2) extensive imbricate thrusting indicates greater compression than would normally be expected from such an intrusion, 3) linear north-south rather than arcuate structural trends are atypical of deformation associated with intrusions unless the intrusion is so large that the arc is essentially straight—so large an intrusion without some other evidence at the surface is unlikely, and 4) the symmetrical outline of the dome suggests concordant intrusion along a horizontal plane that would probably not be present in so complexly deformed a structure.

TABLE 6

Summary of Data on Intrusive Domes (from McKnight 1968: Table 17)

Name of dome	Approximate diameter of dome (feet)	Approximate structural relief (feet)	Form of Intrusion	Strata emplaced in	Time of Intrustion	Additional notes
Corrasco	5,000	500	not exposed; laccolith inferred	Boquillas or lower	after Mitchell Mesa	thoroughly faulted; half covered by Rio Grande flood plain
Tapado	9,000	300	not exposed; possibly laccolith	Boquillas or lower	during Fresno	possibly doming was entirely structural, caused by drag along major bolson fault to southwest
Panther	8,000	700	not exposed; laccolith inferred	Boquillas or lower	during Fresno and Rawls	
Contrabando Lowland Complex	25,000	1,000	laccoliths and sills of diorite and gabbro	Boquillas	during Chisos and perhaps after	see discussion under intrusive rock
Primero	5,000	300	not exposed; laccolith inferred	Boquillas or lower	during Fresno and Rawls	
Segundo	7,000	500	2 laccoliths of latite porphyry	Rawls members 1 and 2	after Rawls member 4	under laccolith is trap door structure
Little	1,000	100	not exposed; laccolith inferred	Rawls member 2 or lower	after Rawls member 8	
Llano	7,000	200	laccolith inferred probably not exposed; possibly basalt mapped as Tcb	below Mule Ear Spring	during Rawls member 4	strata in center are highly contorted, probably independently of intrusion
Bogles	7,000	200	several clustered domes of latite; bases not exposed; laccoliths inferred	upper Fresno and Rawls members 1-4	during upper Fresno through lower part of Rawls member 4	latite fragments in Tfvm are of this rock type
Saucita	15,000 x 3,000	200	clustered laccoliths inferred; top of latite porphyry dome is exposed	upper Chisos to Rawls Tr2lp	after Rawls member 3	exposed intrusion is partly discordant and probably a trap door structure; faults at west end suggest a burried discordant intrusion
Rancherias	11,000	800	probably not exposed, but possibly gabbro (Tig) at west end; may be laccolithic or discordant	Boquillas or lower	mostly before upper Fresno flows	Chisos, Mitchell Mesa, and lower Fresno are absent

APPENDIX 3

MEASURED SECTION 1

Measured up center of south-facing cliff, north of southwest part of Contrabando Lowland on July 30, 1964, with hand level and 6-foot steel tape, by John McKnight (1968, measured section 3).

SUMMARY:	feet	feet
Santana Tuff, Ts		80
Fresno Formation		
covered	83	
trachyandesite, Tfa	270	
undifferentiated, Tf	232	
TOTAL:	585	585
Mitchell Mesa Tuff, Tmm		10
Chisos Formation		
covered	19	
Tule Mountain Member, Tctm	203	
covered	9	
Mule Ear Spring Member, Tcm	20	
undifferentiated, Tc	622	
TOTAL:	873	873
TOTAL MEASURED THICKNESS:		1,548

Unit	Description	Thickness in Feet
MS 3b		
SANTANA TUFF		
	Top of mesa east of triangulation station Madril. Probably 10 to 50 ft of friable tuff normally found in the upper part of the Santana was removed by erosion.	
35.	Tuff. Nonwelded vitric to vitric-crystall tuff with glassy crystals of sanidine and quartz; freshly broken rock is gray, weathers orange; consists of two inferred ash flows of about equal thickness—a 10-ft, soft, friable zone near the center forms a slope between cliffs of well-indurated tuff; the lower 5 ft and upper 10 ft are friable.	80
FRESNO FORMATION		
34.	Covered. Probably tuff and latite porphyry, both of which are abundant in float.	83
33.	Trachyandesite. Gray; speckled with iddingsite; in five gradational zones:	
	e. (top) Scoriaceous, thoroughly altered and weathered to a clinker-like rubble. — 25	
	d. Vesicular; fresh, forms slope. — 45	
	c. Fresh; weathers spheroidally. — 100	
	b. Intensely altered; crumbly; dark-gray; probably argillized; weathers away beneath overhanging cliff in unit "c" above — 60	
	a. Fresh; lower 5 ft slightly vesicular. — 40	
	TOTAL — 270	270
undifferentiated, Tf		
32.	Tuff. Festoon cross-bedded (4-ft maximum amplitude); white to gray; some parts grade to tuffaceous sandstone.	104
31.	Tuff. Faintly-bedded; white to gray; numerous root holes.	128

	Offset section 2,000 ft west across northwest-trending fault to MS 3b. Here Mitchell Mesa is 35 ft thick; Tule Mountain Member, 200 ft; Mule Ear Spring Member, 15 ft.	

MS 3a		
MITCHELL MESA TUFF, Tmm		
30.	Tuff. Nonwelded vitric-crystall tuff with glassy, chatoyant crystals or sanidine; middle part is slightly porcelaneous and forms a nearly vertical cliff; top and base are porous, dull, and friable; pinches out 500 ft to east.	10
CHISOS FORMATION		
29.	Covered. Probably mostly gray tuff—the principal constituent of the float.	19
Tule Mountain Member, Tctm		
28.	Trachyandesite porphyry. Corroded glassy to dull plagioclase phenocrysts in an aphanitic groundmass; groundmass is red-brown where fresh, but it is mostly altered to green or brownish-green celandonitic alteration products; erodes to a jagged cliff, weathering along swirled flow structure to form spalls.	203
27.	Covered. Probably Tule Mountain Trachyandesite Porphyry underlain by pink tuff—both abundant in float.	9
Mule Ear Spring Member, Tcm		
26.	Tuff. Nonwelded vitric tuff with sparse crystals of sanidine and quartz; most is gray and porous, but lower 6 inches and upper foot are buff and friable; forms cliff.	20
undifferentiated Chisos Formation, Tc		
25.	Covered. Probably mostly tuff and sandstone, which are present in float; slope is littered with spalls and slump blocks of Tule Mountain Trachyandesite Porphyry from cliff above.	129
24.	Covered. Probably mudstone, which abounds in float.	6
23.	Mudstone. Faintly-bedded; variegated pink and gray.	30
22.	Sandstone. Thin-bedded pink and gray; a few layers and lenses are conglomeratic sandstone with pebbles of volcanic rock, forms cliff.	33

21.	Tuff. Nonbedded; gray.	18
20.	Tuff. Massive; variegated pink and gray; forms cliff.	4
19.	Tuff. Nonbedded; gray.	9
18.	Tuff. Nonbedded; pink.	3
17.	Tuff. Nonbedded; gray.	1
16.	Mudstone. Thin-bedded; gray.	1
15.	Tuff. Nonbedded; gray.	3
14.	Sandstone. In five massive beds 9 to 15 in thick; gray.	5
13.	Tuff. Nonbedded to faintly-bedded; variegated pink and gray.	10
12.	Sandstone. Festoon cross-bedded with 1 ft amplitude; gray; contains abundant root holes.	7
11.	Sandstone and mudrock. Thin-bedded; fine- to medium-grained, white to gray sandstone interbedded with red-brown to gray-green siltstone and mudstone.	1
10.	Tuff. Nonbedded; variegated white to gray and pale-pink.	19
9.	Tuff. A single massive white bed.	2
8.	Tuff. Nonbedded; gray.	1
7.	Tuff. A single massive white bed.	1
6.	Tuff. Nonbedded; gray.	94
5.	Mudstone. Thin-bedded; pink with gray-green mottling; root holes common.	14
4.	Tuff. Nonbedded; gray.	98
3.	Tuff. Faintly-bedded; pale-pink.	5
2.	Tuff and tuffaceous sandstone. Thin-bedded; gray; about 2/3 is tuff, and the rest medium- to fine-grained sandstone.	15
1.	Tuff. Nonbedded to faintly-bedded; gray, white, and pale-pink.	113
	TOTAL MEASURED THICKNESS:	1,548

Base of section in colluvium; covered Chisos is probably mostly tuff, sandstone, and conglomerate.

APPENDIX 4

MEASURED SECTION 2

Measured up south-facing cliff on north side of Panther Dome on October 17, 1964, with hand level and 6-ft steel tape, by John McKnight (1968, measured section 6).

SUMMARY	feet	feet
Rawls Formation		
member 8, Tr8a	25	
member 7, Tr7at	53	
member 5, Tr5a	48	
member 4, Tr4bp	208	
TOTAL	334	334
Fresno Formation		
latite porphyry, Tflp	102	
latite, Tfl	128	
TOTAL	230	230
Mitchell Mesa Tuff, Tmm		14
Chisos Formation		
undifferentiated, Tc	11	
Tule Mountain Member, Tctm	206	
undifferentiated, Tc	38	
Mule Ear Spring Member, Tcm	11	
undifferentiated, Tc	202	
TOTAL	468	468
TOTAL MEASURED THICKNESS		1,046

Unit	Description	Thickness in Feet

RAWLS FORMATION

Top of cliff. To north, flat-lying Tr9b basalt and Tr9 conglomerate, and sandstone lap with angular unconformity of about 16 degrees onto domed Tr8a trachyandesite of unit 16.

member 8, Tr8a

16. Trachyandesite. Sparse 5 mm plagioclase phenocrysts in a gray aphanitic groundmass; slightly vesicular in upper half; probably a single flow. 25

member 7, Tr7at

15. Tuff. Welded and nonwelded vitric-crystal tuff with glassy crystals in anorthoclase, and accidental fragments of latite porphyry: lower 2 ft is orange palagonitic tuff; next 25 ft is dark-brownish-gray and eutaxitic and forms a nearly vertical cliff; the rest is light brown, light-brownish-gray to gray and friable. 53

member 5, Tr5a

14. Trachyandesite. Aphanitic; gray, several flows; slightly vesicular at base and top of flows. 48

member 4, Tr4bp

13. Trachybasalt porphyry. Corroded and embayed tabular plagioclase phenocrysts as much as 1 in long in a dark-gray, aphanitic matrix speckled with iddingsite; slightly vesicular to scoriaceous; numerous amygdules of calcite and chalcedony; consists of flows of flow-units 5 to 30 ft thick. 163
12. Trachybasalt porphyry. Corroded plagioclase laths up to ½ in long in a dark-gray, aphanitic groundmass; highly vesicular and scoriaceous; weathered to a fine gravel-like rubble; largely covered. 45

Members 1 and 2 of the Rawls Formation are absent here but are present away from the dome; the dome probably stood as a topographic high as they were deposited; Santana Tuff (Ts) thins northward from about 100 ft on the south side of the dome and pinches out about 1,000 ft to the southeast and 200 ft to the west; the dome probably stood topographically high when the Santana was spread also, but the tuff may pinch out on the depositional slope of the underlying latite porphyry flows from the Bofecillos Volcano.

FRESNO FORMATION

latite porphyry, Tflp

11. Latite porphyry. Glassy to dull, corroded and embayed feldspar phenocrysts in a dark-gray, aphanitic matrix; several flows, with highly vesicular bases and tops and vesicular centers; matrix of some flows is speckled with iddingsite; weathers light-gray. 80
10. Trachyandesite porphyry (end member of latite suite). Resembles Tule Mountain Trachyandesite Porphyry—glassy to dull, corroded and embayed plagioclase phenocrysts in a red-brown, aphanitic groundmass—but is not clearly flow-laminated, does not weather in spalls, is more vesicular than typical Tule, and in places is scoriaceous; much is green or brownish-green from celandonitic alteration products; fresh rock weathers dark-brown. 22

latite, Tfl

9. Covered. Probably latite as in unit 8, because it is present in float. 25
8. Latite. Highly vesicular to scoriaceous; dark-gray; forms rubble of sand- to boulder-size fragments; probably several flows; poorly exposed. 103

At least 30 ft of white Fresno tuff is present to west at Panther Spring, but it is absent here, probably because the dome stood topographically high when the tuff was being deposited.

MITCHELL MESA TUFF, Tmm

7. Tuff. Nonwelded vitric-crystal tuff with glassy chatoyant sanidine crystals; white, gray, cream, and buff; top and base are dull and friable; most is highly porcelaneous and cliff-forming. None present 200 ft east, probably because of nondeposition over topographic high developed on Panther Dome. 14

CHISOS FORMATION
undifferentiated, Tc

6. Tuff. Thin-bedded; white to gray. 11

Tule Mountain Member, Tctm

5. Trachyandesite porphyry. Corroded and embayed plagioclase phenocrysts in a dark-red-brown, aphanitic matrix that is partly green from celandonitic alteration products; weathers light-red-brown; spalled along flow structure. 206

undifferentiated, Tc

4. Tuff. Thin-bedded; white. 38

Mule Ear Spring Member, Tcm

3. Tuff. Slightly-welded vitric tuff with glassy crystals of sanidine and quartz; porcelaneous and slightly eutaxitic near center; dull and friable at top and base; white to pink or red-brown; forms cliff. 11

undifferentiated, Tc

2. Tuff and sandstone. Thin-bedded; interbedded white to gray and buff tuff, and thin-bedded tuffaceous sandstone. 147
1. Mudstone. Thin-bedded; red-brown. 55

TOTAL MEASURED THICKNESS: 1,046

Base of section in alluvium of Panther Creek. To south, near center of dome, about 300 ft of poorly exposed Chisos sandstone, mudstone, and tuff are present beneath that measured here.

APPENDIX 5

MEASURED SECTION 3

Measured up east side of Rancherias Canyon, north of northernmost fault of Redford-Lajitas fault zone on September 27, 1964, with hand level and 6-ft steel tape, by John McKnight (1968, measured section 7).

SUMMARY	feet	feet
Rawls Formation		
member 8, Tr8bp	97	
member 5, Tr5a	91	
member 4, Tr4bp	255	
member 2, Tr2t	75	
member 1, Trlb	165	
TOTAL	683	683
Santana Tuff, Ts		99
Fresno Formation		
undifferentiated, Tf	105	
latite porphyry, Tflp	232	
latite, Tfl	151	
trachyandesite	72	
TOTAL	560	560
TOTAL MEASURED THICKNESS		1,342

Unit	Description	Thickness in Feet

RAWLS FORMATION

Top of knob. Mesa 500 ft to east is capped at least 50 ft of festooned trachyandesite of member 8 (Tr8a), which overlies poorly exposed trachybasalt porphyry of member 8 (Tr8bp) in same stratigraphic position as unit 19 (below).

member 8, Tr8bp

19. Trachybasalt porphyry. Like that in unit 15 below. 97

Member 7 (Tr7at) pinches out to north, about 2,000 ft to south; probably on depositional slope of trachyandesite (Tr5a) of unit 18 (below).

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member 5, Tr5a

18. Trachyandesite. Dark-gray; weathers light-gray; in four flows, approximately 30 (lowest), 25, 15, and 20 ft thick–each with vesicular top and base. 91

member 4, Tr4bp

17. Trachybasalt porphyry. Like that in unit 15 below). 106
16. Covered. Probably trachybasalt porphyry. 23
15. Trachybasalt porphyry. Embayed, tabular, glassy, light-gray plagioclase phenocrysts about 1 in long in a black, vesicular groundmass sparsely speckled with iddingsite; weathers red-brown; in flows or flow-units 5 to 20 ft thick; upper and lower parts of flows are scoriaceous; contains numerous amygdules of calcite and chalcedony. 126

member 2, Tr2t

14. Sandstone. Thin-bedded; pink; fine- to medium-grained. 3
13. Tuff. Lithic, with abundant pumice fragments as much as 8 in long, and with sparse fragments of latite porphyry; gray to yellow; probably several ash falls, but poor exposure obscures boundaries. 52
12. Covered. Probably rock like that below. 9
11. Tuff, sandstone, and conglomerate. Intercalated gray, vitric, pumiceous tuff, gray tuffaceous sandstone, and conglomerate of pebble-size rounded and angular fragments of volcanic rock in a matrix of calcite-cemented tuffaceous sandstone. 11

member 1, Trlb

10. Basalt. Black with specks of iddingsite; weathers gray and red-brown; at least 5 flows, each about 30 ft thick; bases and tops of flows form a red-brown rubble of weathered scoria and ash about 5 ft thick. 156
9. Covered. Probably mostly basalt like that above.

Offset section 2,000 ft north.

SANTANA TUFF, Ts

8. Tuff. Vitric, with abundant glassy crystals of sanidine and quartz, with lenticular pumice fragments as much as 5 in long; pale-gray to buff; lower 5 ft and upper 15 ft are friable and nonresistant; the rest forms a nearly vertical cliff that weathers orange. 99

FRESNO FORMATION

undifferentiated, Tf

7. Conglomerate. Resembles unit 5, below, but contains several lenses as much as 1 ft thick and 50 ft long of tuff like that of unit 6 (below). 81
6. Tuff. Faintly-bedded; gray; contains abundant pebble-size inclusions of tuff and volcanic rock; laterally discontinuous–absent several places in about 300 ft of outcrop length. 5
5. Conglomerate. Rounded and angular boulder- to pebble-size fragments of volcanic rock in a matrix of calcitic tuffaceous sandstone. 19

latite porphyry, Tflp

4. Trachyandesite porphyry (end member of latite suite). Resembles Tule Mountain Trachyandesite Porphyry–corroded plagioclase phenocrysts in a red-brown groundmass, here and there green from celandonitic alteration products–but flow

structure less pronounced; weathers red-brown; in three flows, approximately 35 (lowest), 75, and 120 ft thick. 232

latite, Tfl

3. Porphyritic latite. Sparse corroded and embayed feldspar laths up to ½ in long in a light-gray groundmass; two flows, each with vesicular and scoriaceous zones at base and top, approximately 75 (lower) and 55 ft thick. 129

2. Covered. Probably trachyandesite overlain by porphyritic latite. 22

trachyandesite, Tfa

1. Trachyandesite. Dark-gray with iddingsite specks; weathers light-gray and the weathered surface looks granular. 72

TOTAL MEASURED THICKNESS: 1,342

Base of section in alluvium of Rancherias Creek.

APPENDIX 6

MEASURED SECTION 4

Measured up east side of Tapado Canyon about 1 mile northeast of Texas Route 170 on August 24, 1963, with hand level and 6-foot steel tape, by John McKnight (1968, measured section 8).

SUMMARY	**feet**	**feet**
Rawls Formation		
member 7, Tr7at	55	
member 4, Tr4bp	81	
member 2, Tr2t	278	
member 1, Trlb	49	
TOTAL	463	463
Santana Tuff, Ts		140
Fresno Formation		
covered	85	
latite porphyry, Tflp	138	
undifferentiated, Tf	392	
TOTAL	615	615
TOTAL MEASURED THICKNESS		1,218

Unit	Description	Thickness in Feet

RAWLS FORMATION

Top of mesa.

member 7, Tr7at

33. Tuff. Nonwelded to thoroughly-welded vitric-crystal tuff with glassy anorthoclase crystals and accidental fragments of volcanic rock; lower few feet is covered; lowest exposed rock is intensely eutaxitic, black, and cliff-forming tuff that weathers dark-brown; eutaxitic structure dies out about half-way up the ash flow and the upper 15 ft is gray and friable. 55

member 2, Tr2t

32. Covered. Probably trachybasalt porphyry. 23
31. Trachybasalt porphyry. Embayed tabular plagioclase laths as much as 1 in long in a black groundmass speckled with iddingsite; weathers red-brown or gray and granular; vesicles abound; calcite common in fractures and filling amygdules; several flows or flow-units, mostly less than 10 ft thick. 58

memb er 2, Tr2t

30. Covered. Probably tuff. 21
29. Tuff. Resembles that of unit 26, below, but matrix is pink and weathers brown. 23
28. Tuff. Resembles that of unit 26 (below). 32
27. Tuff. Nonbedded; pale-gray; sparse pumice fragments less than 1 in across; very sparse fragments of gray latite are less than ¼ in across. 6
26. Tuff. Nonbedded; pale-gray; contains abundant pumice fragments as much as 10 in across and fresh fragments of latite and latite porphyry as much as 2 in across. 50
25. Tuff. Resembles that of unit 21 (below). 9
24. Tuffaceous sandstone. Well-bedded and partly cross-bedded; some parts conglomeratic with pebble-size fragments of volcanic rock; calcite-cemented. 3
23. Tuff. Resembles that of unit 21 (below). 5
22. Conglomerate. Pebble-size fragments of volcanic rock in a matrix of calcite-cemented tuffaceous sandstone; gray; 2 feet of relief on lower contact in 10 ft of outcrop length. 3
21. Tuff. Nonbedded; contains pumice fragments as much as 2 in across and fragments of latite porphyry as much as ½ in across; white; weathers buff. 75
20. Conglomerate. Pebble-size fragments of volcanic rock in a matrix of calcite-cemented tuffaceous sandstone; different parts are well-bedded, poorly-bedded, and cross-bedded. 25
19. Covered. Probably tuff. 20
18. Tuff. Nonbedded; contains pumice fragments up to 1 in in diameter and smaller fragments of latite and latite porphyry. 6

member 1, Trlb

17. Basalt. Black with iddingsite specks; in three flows, 12 (lowest), 23, and 14 ft thick; each flow has a red-brown tuffaceous and scoriaceous basal flow breccia up to 2 ft thick with abundant calcite amygdules, a middle part consisting of black basalt with prominent horizontal flow laminae, and an upper rubble 1 to 4 ft thick of black vesicular and scoriaceous basalt fragments of interstitial red-brown tuff. 49

SANTANA TUFF, Ts

16. Covered. Probably tuff. 8
15. Tuff. Partly-welded vitric tuff with abundant glassy crystals of sanidine and quartz and with pumice fragments as much as 6 in across; lower 85 ft is intensely eutaxitic, porcelaneous, pale-gray tuff that weathers orange to dark-brown, and forms a steep cliff; upward, above a 15-ft transition zone, is 17 ft of dull friable nonfoliated tuff that weathers buff and forms a gentle slope; the upper 15 ft (here arbitrarily included in the Santana) is faintly-bedded white to gray tuff devoid of

crystals and pumice fragments–it may be an ash fall following, but associated with, the Santana ash flows. 132

FRESNO FORMATION

14. Covered. Probably top of latite porphyry, overlain by tuff and sedimentary rock, overlain by the base of the Santana. 85

latite porphyry, Tflp

13. Trachyandesite porphyry (end member of latite suite). Closely resembles Tule Mountain Trachyandesite Porphyry–corroded, glassy plagioclase phenocrysts in a red-brown matrix; partly green from celadonitic alteration products; weathers to spalls formed on swirled flow structure. 138

undifferentiated, Tf

12. Covered. Probably tuff. 68
11. Tuff. Faintly-bedded; pale-green to light-green. 51
101 Tuff. Thin-bedded; white. 1
9. Tuff. Faintly-bedded; very pale-green to light-green. 23
8. Tuff. Thin-bedded; pale-green to white. 22
7. Tuff. Faintly-bedded and festoon cross-bedded like unit 6 below; light-green; grades from unit 6 below. 17
6. Tuff. Faintly-bedded and festoon cross-bedded; pale-green at base to vivid light-green at top. 114
5. Tuff. Resembles unit 3 below. 9
4. Mudstone. Thin-bedded; pale-red-brown. 2
3. Tuff. Thin-bedded and festoon cross-bedded; white; weathers buff. 21
2. Tuff. Nonbedded; white to gray; weathers buff. 14
1. Tuff. Festoon cross-bedded (3-foot maximum amplitude); white, buff, and pale-green; root holes aboud. 50

TOTAL MEASURED THICKNESS: 1,218

Base of section in alluvium of Tapado Creek.

APPENDIX 7

MEASURED SECTION 5

Measured on east side of Tapado Canyon on east flank of Tapado Dome, about 2 miles south of Tapado Spring on September 3, 1964, with hand level and 6-foot steel tape, by John McKnight (1968, measured section 9).

SUMMARY	feet	feet
Santana Tuff, Ts		44
Fresno Formation, undifferentiated		404
Mitchell Mesa Tuff, Tmm		25
Chisos Formation		
Tule Mountain Member, Tctm	167	
basalt, Tcb	109	
undifferentiated, Tc	306	
TOTAL	582	582
TOTAL MEASURED THICKNESS		1,055

Unit	Description	Thickness in Feet
SANTANA TUFF, Ts		
	Top of mesa. Rawls members 1 and 2 are present in cliff ½ mile to north.	
24.	Tuff. Partly-welded vitric-crystal tuff with glassy crystals of sanidine and quartz; eutaxitic and red-brown from 4 to 30 ft above base; rest is buff or gray, friable, and weathers orange; base undulates–thickness ranges from a few feet to about 100 ft in a few hundred feet of outcrop length.	44
FRESNO FORMATION		

	The Fresno Formation thickens appreciably to south, indicating uplift of Tapado Dome before, or more probably during, the deposition of the Fresno.	
	A flow of trachyandesite resembling the Tule Mountain Trachyandesite porphyry is present beneath the Santana 300 ft to the north and ½ mile to the south; it probably fills gullies eroded in the soft Fresno tuff.	
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undifferentiated, Tf		
23.	Tuff. thin-bedded; gray.	3
22.	Tuff. Pumiceous with abundant sanidine crystals; nonbedded, friable, pale-gray.	2
21.	Tuff. Nonbedded; buff.	6
20.	Conglomerate. Rounded to angular boulder- to pebble-size fragments of volcanic rock in a matrix of tuffaceous sandstone.	12
19.	Tuff. Faintly to clearly thin-bedded; white to pale-gray.	27
18.	Conglomerate. Like that of unit 16.	5
17.	Tuff. Thin-bedded; white.	17
16.	Conglomerate. Rounded to angular pebble- to cobble-size fragments of volcanic rock in a matrix of tuffaceous sandstone.	16
15.	Tuff. Faintly to clearly thin-bedded and festoon cross-bedded, white, gray, gray-green, and light-green; contains sparse pebble-size pumice fragments.	300
MITCHELL MESA TUFF, Tmm		
14.	Tuff. Nonwelded vitric-crystal tuff with glassy, chatoyant sanidine crystals; gray to buff; weathers red-brown; ranges from 2 to 40 ft thick in 300 ft of outcrop length.	25
CHISOS FORMATION		
Tule Mountain Member, Tctm		
13.	Trachyandesite porphyry. Corroded plagioclase phenocrysts in a red-brown matrix with olive-green mottling caused by celandonitic alteration products; swirled flow structure is accentuated by weathering and jointing.	167
basalt, Tcb		
12.	Breccia. Weathered, scoriaceous, pebble-size fragments of basalt cemented by calcite; probably rubble at top of basalt flow(s) of unit 11 (below).	13
11.	Basalt. Thoroughly-weathered; crumbly; red-brown; probably different flow(s) than basalt below.	78
10.	Basalt. Black; contains sporadic patches with abundant amgdules of calcite and chalcedony; lower 5 ft is a calcite-cemented breccia of vesicular, amygdaloidal, and scoriaceous basalt.	18

	About 30 ft of Mule Ear Spring Tuff (lowest) and 2 and 7 ft of the welded and microcrystal tuffs described in the text are present along Tapado Creek, about 1,000 ft to the southeast; their absence here suggests uplift of Tapado Dome before they were deposited.	
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undifferentiated, Tf		
9.	Tuff. Nonbedded; friable; pink.	10
8.	Conglomerate and sandstone. Interbedded; tuffaceous sandstone and conglomerate of rounded to angular boulder- to pebble-size fragments of volcanic rock with interstitial sandstone.	10
7.	Tuff. Contains abundant pumice fragments as much as 6 in across; nonbedded; pale-gray; root holes abound.	135

6. Mudstone and siltstone. Intercalated; thin-bedded; gray, gray-green and pink–siltstone is mostly pink, and mudstone is mostly gray or gray-green. 6

5. Tuffaceous sandstone. Thin-bedded and partly cross-bedded; gray-green; root holes abound; coarse at base grading to fine at top; contains sparse stringers and lenses of conglomerate with pebble-size fragments of volcanic rock. 30

4. Sandstone and siltstone. Interbedded; thin-bedded; gray-green, tuffaceous sandstone and red-brown siltstone. 5

3. Sandstone. Tuffaceous; thin-bedded; pale-gray to gray-green. 5

2. Conglomerate. Angular to sub-rounded pebble- to boulder-size fragments of volcanic rock and rounded limestone pebbles with interstitial tuffaceous sandstone. 2

1. Sandstone and siltstone. Intercalated, thin-bedded siltstone and fine sandstone; tuffaceous; pink and gray-green; root holes abound. 3

TOTAL MEASURED THICKNESS: 1,055

Base of section in alluvium of Tapado Creek.

APPENDIX 8

MEASURED SECTION 6

Measured up east side of Burro Canyon, ½ mile upstream from north side of Redford Bolson on September 12, 1964, with hand level and 6-foot steel tape, by John McKnight (1968, measured section 10).

SUMMARY	feet	feet
Rawls Formation		
member 9, Tr9b		50
member 8		
Tr8a		20
Tr8bp		30
member 7, Tr7at		80
member 4, Tr4bp		200
member 2, Tr2t		320
member 1, Trlb		110
TOTAL MEASURED THICKNESS:		810

Unit	Description	Thickness in Feet

RAWLS FORMATION

Top of mesa

member 9, Tr9b

18. Basalt. Black with specks of iddingsite; three or more flows with thin layers of conglomeratic tuffaceous sandstone between. — 50

member 8, Tr8a, and Tr8bp

17. Trachyandesite. Dark-gray; a single flow; festooned flow structure near top. — 20
16. Trachybasalt porphyry. Resembles that of unit 12 (below). — 30

member 7, Tr7at

15. Tuff. Partly-welded vitric-crystal tuff with glassy anorthoclase crystals in a matrix speckled with hydrated iron oxides; lower 3 ft is friable, orange and palagonitic; the next 15 ft are cliff-forming, dark-gray, and eutaxitic with the structure dying out upward; the rest grades in a few feet above the eutaxitic zone to slope-forming gray to brownish-gray friable tuff. — 80

member 4, Tr4bp

14. Trachybasalt porphyry. Embayed plagioclase phenocrysts in a black matrix speckled with iddingsite; many flows or flow-units from 5 to 30 ft thick, each with a vesicular, scoriaceous, or amygdaloidal base and top. — 180
13. Covered. Probably trachybasalt porphyry. — 10
12. Trachybasalt porphyry. Corroded and embayed plagioclase laths as much as 1 in long in a dark-gray matrix speckled with iddingsite; probably part of a single flow or flow-unit; lower few feet vesicular with sparse chalcedonic amygdules. — 10

member 2, Tr2t

11. Tuff. Pumiceous; faintly thick-bedded; gray. — 20
10. Latite porphyry (not mapped). Trachytic plagioclase laths in a gray matrix speckled with iddingsite; lower 3 and upper 20 ft are vesicular. — 55
9. Sandstone and conglomerate. Tuffaceous; intercalated; contains clasts of volcanic rock; well-bedded and cross-bedded with channels here and there. — 45
8. Tuff. Massive with pumice fragments as much as 4 ft across; gray to buff; weathers orange; forms cliff. — 30
7. Sandstone and conglomerate. Intercalated; conglomerate of pebble-size clasts of volcanic rock with interstitial tuffaceous sandstone, and well-bedded and cross-bedded gray tuffaceous sandstone. — 5
6. Tuff. Faintly thin-bedded; gray. — 5
5. Conglomerate. Angular pebbles of volcanic rock in a matrix of tuffaceous sandstone. — 5
4. Tuff. Mostly massive; friable; brown to orange; abundant pumice fragments as much as 1 in across; lower 5 ft is well-bedded; forms cliff; upper part weathers with large rounded caves. — 25
3. Tuff. Massive; orange; abundant pumice fragments as much as 1 in across; base is a well-defined stratum. — 95
2. Tuff. Massive; pale-yellow to buff; sparsely pumiceous, with fragments mostly less than ½ in across. — 35

member 1, Trlb

1. Basalt. Speckled with iddingsite; at least three flows with upper and lower parts vesicular, scoriaceous and slope-forming, and middle parts massive and cliff-forming; top 5 ft of uppermost flow is rubble of scoria fragments with interstitial tuff–percentage of tuff increases upward (ca. 10 to 80%), but contact with overlying tuff of member 2 is sharp. — 110

TOTAL MEASURED THICKNESS: 810

Base of section in alluvium of Burro Creek.

APPENDIX 9

MEASURED SECTION 7

A 205-ft section of Rawls member 7 ash-flow tuff (Tr7at) measured up north side of upper Bofecillos Canyon northeast of Burro triangulation station on October 30, 1966, with hand level and 6-foot steel tape, by John McKnight (1968, measured section 11).

Unit	Description	Thickness in Feet

Top of section at base of 2-ft thick basal flow breccia of Rawls member 8 trachyandesite (Tr8a).

RAWLS MEMBER 7
ash-flow tuff (Tr7at).

Except as noted, the rock is massive, brownish-gray, irregularly jointed and of essentially the same composition from base to top (Table 6); adjacent units and sub-units are gradational. The tuff differs mostly in induration and foliation, a variation from which individual ash flows are inferred. Except possibly for units 1, 2, 3, and 21, the rock is probably in the zone of vapor-phase crystallization as defined by Smith (1960b).

21. Tuff; probably ash-fall. Friable, light-brownish-gray; pumice fragments up to 1 in across are sparser than in rock below; faint-bedding or horizontal jointing; forms gentle, partly covered slope with no ledges. 23
20. Slightly-welded ash flow. Lower 2 ft contains blocks of trachybasalt porphyry as much as 1 ft across; forms steep rounded cliff. 8
19. Slightly-welded ash flow. 10
18. Nonwelded ash flow. Well indurated in center. 6
17. Nonwelded ash flow. Friable. 3
16. Slightly-welded ash flow. 8
15. Nonwelded ash flow. Friable, forms slope with no cliff developed on middle part; largely covered. 17
14. Slightly-wlded ash flow. Red-brown, porous, with slightly eutaxitic 1-ft zone in middle. 8
13. Moderately-welded ash flow. In five sub-units:
    - e. Nonwelded tuff. Friable. 5 feet
    - d. Slightly-welded tuff. Slightly eutaxitic. 5 feet
    - c. Moderately-welded tuff. Moderately eutaxitic 4 feet
    - b. Slightly-welded tuff. Slightly eutaxitic. 2 feet
    - a. Nonwelded tuff. Friable. 1 foot
    - TOTAL 17 feet 17
12. Slightly-welded ash flow. 4
11. Slightly-welded ash flow. 5

Unit 10 is the top of the cliff-forming part of the member 7 ash flows. Ash flows above are generally thinner and composed mostly of nonwelded tuff with a slightly-welded zone in the middle less than 2 ft thick; they form rounded steps and benches up the slope. Unless otherwise stated, ash flows above have this approximate zonation.

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10. Moderately-welded ash flow in three sub-units:
    - c. Slightly-welded to nonwelded tuff. Similar to 4d 1 foot
    - b. Slightly- to moderately-welded tuff. Similar to 4c. 11 feet
    - a. Nonwelded to slightly-welded tuff. Similar to 4b 3 feet
    - TOTAL 15 feet 15
9. Moderately-welded ash flow. Three sub-units about equally thick and except for relative thicknesses, similar to 4b, 4c, and 4d. This unit pinches out about 100 ft to east and to west. 2
8. Thoroughly-welded ash flow. In five sub-units:
    - e. Nonwelded tuff. Similar to 4d. 1 foot
    - d. Slightly-welded tuff. Similar to 4b but welding decreases upward. 6 feet
    - c. Moderately- to thoroughly-welded tuff. Well indurated, dull, moderate to intense eutaxitic structure greatest in center. Weathers to smooth near-vertical cliff. 12 feet
    - b. Slightly-welded tuff. Well indurated, slightly eutaxitic; unit forms rought pitted cliff. 6 feet
    - a. Nonwelded tuff. Slightly triable, unit forms slope. 2 feet
    - TOTAL 27 feet 27
7. Moderately-welded ash flow. In four sub-units:
    - d. Nonwelded tuff; similar to 4d. 1 foot
    - c. Slightly- to moderately-welded tuff. Similar to 4c. 3 feet
    - b. Slightly-welded tuff. Similar to slightly eutaxitic upper part of 4b. 2 feet
    - a. Nonwelded tuff. Continuous with and similar to 6c; boundary between ash flows inferred. 0.5 feet
    - TOTAL 2 feet 6.5
6. Moderately-welded ash flow. In three sub-units:
    - c. Nonwelded tuff similar to 6a and continuous with 7a thick. .5 feet
    - b. Slightly- to moderately-welded tuff. Similar to 4c. 1 foot
    - a. Nonwelded tuff. Similar to and continuous with 5c. .5 feet
    - TOTAL 2 feet 2
5. Moderately-welded ash flow. Unit thickens to eash and forms single cooling unit with unit 4 (below); pinches out 100 yards to west. In three sub-units:

c. Nonwelded tuff. Friable; this unit is lower half of nonwelded zone between welded zones—boundary between ash flows is inferred; unit is relatively nonresistant—forms slope; 6 in thick. .5 feet
b. Slightly- to moderately-welded tuff. Similar to 4c (below). 3 feet
a. Nonwelded tuff. Continuous with and similar to 4d (below), but inferred in ash flow of unit 5. 2 feet
TOTAL 5.5 feet 5.5

4. Moderately-welded ash flow. In four sub-units:
d. Slightly-welded to nonwelded tuff. Well indurated at base to slightly friable at top; slight eutaxitic structure dies out upward. 2 feet
c. Slightly- to moderately-welded tuff. Well indurated, slight to moderate eutaxitic structure greatest in center; forms near-vertical cliff with smooth dull surface.
b. Nonwelded to slightly-welded tuff. Grades from slightly friable to nonfoliated at base to well indurated and slightly eutaxitic at top. Contains about 5% angular trachyandesite blocks, mostly 3 to 4 in across, but as much as 8 in; unit weathers to near vertical cliff with rough surface around trachyandesite fragments. 8 feet
a. Nonwelded tuff. Friable, pink tuff similar to unit 3 (below); relatively nonresistant—sub-unit above overhangs as much as 6 ft. 4 feet
TOTAL 25 feet 25

3. Nonwelded ash flow. Palagonitic tuff similar to unit 2 (below) but grades upward from orange to pink; top forms nearly horizontal ledge. 4
2. Nonwelded ash flow. Yellow-brown to orange slightly friable palagonitic tuff; forms vertical cliff with 3 (above) and base and top are eroded back into the face. 2
1. Transition zone. Lower 3 ft mostly Tr5a trachyandesite blocks up to 2 ft across from top of flow below with interbedded and interstitial brown tuffaceous sandstone; upper 4 feet is predominantly brown tuff and tuffaceous sandstone. 7

TOTAL MEASURED THICKNESS: 205

Base of section in Tr5a trachyandesite.

APPENDIX 10

MEASURED SECTION 8

Measured up west side of mesa east of Cuevas Amarillas Spring, on August 9, 1963, with hand level and 6-foot steel tape, by John McKnight (1968, measured section 12).

SUMMARY	feet	feet
Rawls Formation		
member 8, Tr8a		176
member 7, Tr7at		255
member 4, Tr4bp		256
member 2, Tr2t		166
member 1, Trlb		20
Total measured thickness:		823

Unit	Description	Thickness in Feet
RAWLS FORMATION		
Top of mesa.		
member 8, Tr8a		
20.	Trachyandesite. Sparse corroded milky plagioclase laths in a gray groundmass; swirled flow structure faintly visible in top 20 ft.	176
member 7, Tr7at		
19.	Covered. Probably tuff.	156
18.	Tuff. Intergradational well-bedded and massive; gray; some layers contain abundant fragments of scoriaceous basalt. This tuff is included in member 7, because it correlates with tuff at the base of member 7, on the north side of Bofecillos Canyon, about ½ mile to the north–it is probably ash-fall, rather than ash-flow tuff, but is arbitrarily included in Tr7at ash-flow tuff.	37
17.	Covered. Probably tuff.	62
member 4, Tr4bp		
16.	Trachybasalt porphyry. Corroded and embayed tabular plagioclase phenocrysts in a black to gray groundmass speckled with iddingsite; mostly vesicular or scoriaceous with amygdules of chalcedony, moss agate, and calcite; about 14 flows or flow-units ranging from less than 1 ft to about 30 ft thick, with cliff-forming middles of flows relatively less scoriaceous or vesicular than slope-forming bases and tops; as much as 18 ft of tuff laden with scoriaceous basalt fragments may be present between flows; the basalt weathers brown or gray, except in the few feet above or below flows where it commonly weathers red-brown.	256
member 2, Tr2t		
15.	Tuff. Pumiceous; altered by overlying lava flows: upper half is red-brown and contains rusty scoriaceous basalt fragments from overlying flow; lower half is white to buff and chalky textured.	6
14.	Covered. Probably tuff.	15
13.	Tuff. Well-bedded with beds from 1 to 15 ft thick; gray; pumiceous with maximum fragment size ranging from 0.1 to 3 in in different beds.	37
12.	Tuff. Thin-bedded with sparse pebble-size fragments of pumice; pale-yellow.	5
11.	Tuff. Massive; pumiceous; gray.	17
10.	Conglomerate. Pebbles of volcanic rock and pumice in a matrix of tuff and tuffaceous sandstone; poorly-bedded, except for upper 6 in which is well bedded; gray.	4
9.	Tuff. Pumiceous with fragments as much as 2 in across; massive; pale-yellow to buff.	72
8.	Tuff. Pumiceous; thick-bedded; gray; contains intercalated lenses of conglomerate sandstone like that in unit 7, below.	5
7.	Conglomeratic sandstone. Pebbles and cobbles of volcanic rock and pumice sparsely distributed in calcite-cemended tuffaceous sandstone; gray.	2
6.	Tuff. Pumiceous; massive; gray.	5
5.	Conglomeratic sandstone. Pebbles of volcanic rock in a matrix of tuffaceous sandstone; well bedded; gray.	1
4.	Tuff. Vitric-lithic, with abundant granule-size fragments of latite and latite porphyry; pumiceous; measive; buff.	22
3.	Tuff. Pumiceous; massive; pale-buff.	23
2.	Covered. Probably basalt overlain by tuff.	10
member 1, Trlb		
1.	Basalt. Slightly porphyritic, with narrow glassy plagioclase laths as much as ½ in long in a black groundmass speckled with iddingsite; several flows; base not exposed.	20
	TOTAL MEASURED THICKNESS:	823

Base of section in alluvium of Bofecillos Creek.

APPENDIX 11

MEASURED SECTION 9

Measured up three cliffs at mouth of Bofecillos Canyon, 2,000 ft (MS 13a), 1,500 ft (MS 13b), and 500 ft (MS 13c) downstream from Bofecillos Spring on August 21, 1963, with hand level and 6-ft steel tape, by John McKnight (1968, measured section 13).

SUMMARY	feet	feet
Rawls Formation		
member 7, Tr7at	45	
member 4, Tr4bp	306	
member 2, Tr25	111	
member 1, Trlb	51	
TOTAL	513	513
Fresno Formation, Tf		29
TOTAL MEASURED THICKNESS		542

Unit	Description	Thickness in Feet

MS 13c

RAWLS FORMATION

Top of cliff. About 50 ft of member 9 basalt (Tr9b) overlies about 100 ft of member 8 trachyandesite on the flats about 1,000 ft to the north.

member 7, Tr7at

15. Tuff. A single welded ash flow of pumiceous vitric tuff with sparse glassy crystals of anorthoclase; base—lower 2 ft or so—is covered; the lower half of the ash flow is cliff-forming grownish-black tuff with splotches of red-brown hydrated iron oxides, and grades upward from welded, strongly eutaxitic tuff below to nonwelded, nonfoliated tuff at the middle of the ash flow; upper half is slope-forming, friable, gray tuff. — 45

member 4, Tr4bp

14. Trachybasalt porphyry. Corroded and embayed tabular or lath-shaped plagioclase phenocrysts 0.5 to 2 in long in a black to gray groundmass speckled with iddingsite; at least 12 flows or flow-units, the thickest of which is about 40 ft; tops and bottoms of flows are vesicular with amygdules or calcite and chalcedony; many fractures are filled with calcite. — 306

Offset 1,000 ft west to MS 13c on south side of Bofecillos Creek, 500 ft downstream from Bofecillos Spring.

MS 13b

member 2, Tr2t

13. Tuff. Vitric, with pebble-size fragments of pumice and sparse pebble-size fragments of latite and latite porphyry; massive; gray. — 5
12. Tuff. Pumiceous; massive; buff. — 12
11. Tuff. Vitric and pumiceous, with abundant pebble-size fragments of altered latite. — 17
10. Tuff. Pumiceous; massive; white at base, grading to buff at top. — 70
9. Tuff. Pumiceous; well-bedded and thin-bedded; buff. — 7

Offset 500 ft northeast to MS 13b on southeast side of Bofecillos Creek, where member 1 basalt (Trlb) is 42 ft thick; the top of the flow resembles the top at MS 13a.

MS 13a

member 1, Trlb

8. Basalt. A single flow consisting of: 1) a red-brown-weathering basal flow breccia, 2 ft thick, of fragments of basalt with interstitial tuff in the lower foot, 2) the black main part of the flow with prominent joints along horizontal flow laminations, and prominent vertical joints, and 3) a black rubble of basalt fragments, 13 ft thick, with white interstitial tuff in the top 3 ft. — 51

FRESNO FORMATION, Tf

7. Tuff. Sparsely pumiceous; massive; grades upward from pale-buff to brown, perhaps as a result of baking by overlying basalt. — 6
6. Conglomeratic sandstone. Rounded pebbles and cobbles of volcanic rock and sparse pebbles of limestone in a matrix of calcite-cemented tuffaceous sandstone; middle 2 ft is only slightly conglomeratic. — 8
5. Tuff. Massive; white. — 3
4. Conglomerate. Rounded fine pebbles of volcanic rock and limestone in a matrix of calcite-cemented tuffaceous sandstone; poorly bedded; gray. — 1
3. Tuff. Massive; partly argillized; white. — 5
2. Tuff. Vitric, with sparse angular fragments of volcanic rock as much as 0.2 in across; massive; white. — 4
1. Conglomerate. Angular to rounded pebbles of volcanic rock and about 1% rounded pebbles of micritic limestone in a matrix of calcite-cemented tuffaceous sandstone; massive; gray; base not exposed. — 2

TOTAL MEASURED THICKNESS: 542

Base of section. Alluvium of Bofecillos Creek.

THE VEGETATION OF THE BOFECILLOS MOUNTAINS: A PRELIMINARY SURVEY

Mary Butterwick and Jim Lamb

INTRODUCTION

The Bofecillos Mountains, situated in the southeastern portion of Presidio County, occupy the southern half of the Big Bend Ranch. At the heart of these mountains is the Bofecillos Volcano, a dissected cone approximately 20 km across. Volcanism here during the Tertiary Time is responsible for rocks in this mountain range. The activity of regional uplift, faulting, and subsequent wind and water erosion has resulted in a varied topography composed of steep-walled canyons, mesa tops, and interrupted ridges, along with colluvial and alluvial plains. The plants inhabiting these diverse geological features tend to form recognizably distinct units. Sotol (*Dasylirion texanum*) and Lechuguilla (*Agave lecheguilla*) frequent the slopes as do a diversity of grass species and shrubs including Resin Bush (*Viguiera stenoloba*), Oregonillo (*Aloysia wrightii*), *Bernardia obovata, Cassia wislizenii,* and Engelmann Prickly Pear (*Opuntia phaeacantha*). The surrounding plains are dominated by Creosote Bush (*Larrea tridentata*) and *Acacia neovernicosa,* with scattered individuals of Ocotillo (*Fouquieria splendens*), Mesquite (*Prosopis glandulosa*), Catclaw Acacia (*Acacia greggii*), and Cat's Claw Mimosa (*Mimosa biuncifera*). Canyons of the southern Bofecillos provide a relatively mesic environment that allows for the presence of water-loving species such as Fresno (*Fraxinus velutina*), Chapa (*Populus arizonica*), Southwestern Black Willow (*Salix gooddingii*), Apache Plume (*Fallugia paradoxa*), and Burro-Brush (*Hymenoclea monogyra*). Numerous species of herbaceous annuals and perennials are found throughout the Bofecillos. Some of the more frequently-encountered taxa include *Ruellia parryi,* Violet Sida (*Sida filicaulis*), Bluntscale Bahia (*Bahia pedata*), Desert Baileya (*Baileya multiradiata*), Leatherweed Croton (*Croton pottsii*), *Talinopsis frutescens,* and Mariola Parthenium (*Parthenium incanum*).

Of the diverse flora found in these mountains during the survey, the grasses apparently had benefited the most from recent seasonal rains. Side-Oats Grama (*Bouteloua curtipendula*), Arizona Cottontop (*Trichachne californica*), Slim Tridens (*Tridens muticus*), Tanglehead (*Heteropogon contortus*), and Green Sprangletop (*Leptochloa dubia*) all appeared to be at the height of their yearly development.

METHODS

Two methods of evaluating the vegetation of this area were employed. Plant specimens were collected throughout in an effort to determine the qualitative nature of the flora. Determination of the species was aided by the *Manual of the Vascular Plants of Texas* (Correll and Johnston 1970) and the *Manual of the Grasses of the United States* (Hitchcock 1950). These specimens have been deposited in the University of Texas Herbarium for future reference.

A quantitative sampling was also carried out by means of vegetation transects. Eight sites were chosen as representative of various environmental forms in the Bofecillos, i.e., slopes of various orientation to the sun, mesa tops and alluvial flats. The quadrat plot method was used in accordance with Curtis and Cottam (1965). A 0.1-m quadrat (a rectangular metal frame) was placed along a 100-m tape at 10-m intervals. At each interval, the number of species falling within the quadrat and the percentage of ground covered by each were recorded. The 100-m tape was then moved 10-m to the side to form a parallel line, and the procedure was repeated. Additional lines were run until no new species were encountered. From these data it was possible to calculate the numerical frequency of each species, ground area covered by all plants, relative frequency, and relative dominance among the species. (Appendix II). Data presented in this report are based on field studies carried out between September 26 and October 13, 1975.

DISCUSSION

With the annexation of Texas and the subsequent establishment of forts along the western frontier, botanical explorations into the Trans-Pecos region were made possible. Charles Wright, accompanied by federal troops, collected extensively in the Southwest between 1849 and 1852. Another investigator of western plants, John Torrey (1858), wrote, in conjunction with the United States-Mexican boundary survey, the "Botany of the Boundary," based on the specimens collected by Wright and the other survey botanists, including C. C. Parry, J. M. Bigelow, and A. Schott. Following the turn of the century, William Bray (1905) and Mary S. Young (1914), both professors at the University of Texas, published articles dealing with the ecology and botany of the Trans-Pecos region, but none specifically dealt with the Bofecillos Mountains. Barton Warnock (1970), a professor of Botany at Sul Ross University and a specialist on West Texas flora, recently completed a botanical treatment of the Big Bend area. The Bofecillos Mountains in particular have thus far been scantily botanized, although incidental collections are known from this area.

Climatic conditions found in the Bofecillos Mountains are those typical of a desert environment. Water is limited, with a mean annual precipitation of about 20-30 cm and an evaporation rate of over 2 m a year, the highest rate found in the state. Mean annual temperatures are 18°-19°C, and the warm season, that is days in which temperatures remain above freezing, extends from 230 to 245 days of the year. The intensity of sunlight is indicated by a mean annual possible sunshine of 70%-80% (Arbingast 1973).

Plants, being primarily sedentary organisms, are particularly susceptible to the effects of such severe climatic conditions. The plants' ability to deal with the harsh demands of a desert habitat by means of cryptic physiological and/or observable morphological characteristics is the prime force in determining their survival and geographical distribution. Many of the plants of the Bofecillos exhibit well-known adaptations to xeric environments. Presence of storage tissue is found in numerous species. Cacti are noted for their fleshy stems which retain food and water. Such substances are stored in the leaf bases of Lechuguilla and Spanish Dagger, while Sotol and Bear Grass utilize their roots and woody bases. Umbrella-wort (*Allionia incarnata*), Angel-Trumpets (*Acleisanthes longiflora*), and *Talinopsis frutescens* are herbaceous perennials with tuberous roots for storage and with stems which develop only under favorable conditions. Ocotillo, whose woody stems maintain food reserves, sheds its leaves during dry periods in order to retard water loss by transpiration. Transpiration losses are thought to be decreased by reduction of the leaf surface, as exemplified by the Acacias, Cat's Claw Mimosa, Mesquite, White Ratany (*Krameria grayi*), and Dalea (*Dalea formosa*). The rate of water-loss may be retarded by the presence of resinous coatings on the leaves of Creosote, Tarbush (*Flourensia cernua*), and Resin Bush. Annual plants are able to remain in dormancy as a seed until the proper conditions of moisture and temperature exist to stimulate germination. Notable examples include *Nama hispidum*, Desert Baileya, Six-weeks Grama (*Bouteloua barbata*), and Six-week Three-awn (*Aristida adscensionis*).

The canyons of this study area typically exhibit more hospitable conditions due to a greater water supply and protection from wind and sunlight. Many of the plants inhabiting these canyons have not undergone the necessary adaptations for survival on the neighboring slopes and plains. Such plants are highly restricted in their distribution and are considered to be relics from a time when the region featured a more mesic climate.

In dealing with a xeric environment such as exists in the Bofecillos, the availability of water, exposure to the elements, and soil texture are all important factors in determining distributions of many of the plants. Each major type of terrain—mountain slope, mesa, alluvial or colluvial gravel, riparian, and canyon—showed not only characteristic environmental factors but also distinguishable aggregations of plants. Thus, five major plant associations were recognized in this study, each corresponding to one of the major topographic areas. There was no homogeneity of plants throughout a given plant association. The composition of plant species often varied noticeably from one area to another. Fluctuations in plant populations, possibly random or mediated by desease, local drought, or overgrazing, could account for such local variations. No rigid boundaries could accurately be drawn between any two plant associations, for many plants characteristic of one association were not necessarily found there exclusively. In fact, a group of plants, including Resin Bush, Creosote, Mesquite, and the Opuntias was ubiquitous throughout the Bofecillos. In general, however, the major plant associations were dependent upon and contiguous with the major types of terrain to be discussed below.

THE SLOPE ASSOCIATION

Distinguished by its diversity of grasses and other herbaceous species, the Slope Association displays a relative luxuriance when compared to the surrounding plains. Sampling of this association consisted of a series of five quadrat transects run primarily in the eastern portion of the Bofecillos (Tables 1, 3, 5, 7; Figs. 1, 3, 5, 7). Limited time and inaccessibility made further sampling in the western Bofecillos unfeasible. The sites were chosen at different orientations to the sun to determine possible correlations with the plant composition. In general, no relationship was observed except for the presence of *Selaginella wrightii* on north-facing transect slopes. At one site *Selaginella* was the dominant herb, showing a relative dominance of 4.53% (Table 1). Although this plant is not exclusively found on north-facing slopes, the partial protection from direct sunlight and increased exposure to winter moisture may enhance its relative abundance on these slopes.

Data obtained from the adjoining study areas on the Big Bend Ranch indicate that the seasonal rains stimulate the development of several of the grass species observed. A similar trend is observed in the Bofecillos for Arizona Cottontop, Tanglehead, Black Grama (*Bouteloua eriopoda*), and Green Sprangletop which, along with the annual Six-weeks Three-awn, frequent the slopes. Side-Oats Grama is a dominant grass throughout the association, in addition to Blue Three-awn (*Aristida glauca*), Common Curlymesquite (*Hilaria belangeri*), Black Grama, and Chino Grama (*Bouteloua ramosa*) which are locally dominant at their respective sites. The percentage grass cover ranges from 22.64% to 32.04% (Tables 4 and 5). These values probably approach the optimal growth potential of the grasses characterizing this association. However, these relatively inaccessible slopes have not remained unaltered by the grazing of livestock. The abundance of typically invading species such as Broomweed (*Xanthocephalum microcephalum*), *Croton pottsii*, Engelmann Prickly Pear, Resin Bush, and Oregonillo are evidence of a partial deterioration of the grassland.

A high diversity of herbaceous annuals and perennials inhabit the slopes. *Verbena neomexicana*, Mariola Parthenium, Bluntscale Bahia, Littleleaf Abutilon (*Abutilon parvulum*), and Desert Baileya are present in abundance.

Values for Total Raw Coverage range from 55.56% to 71.2%. The fact that the surface of the slope is extremely rocky, thereby limiting the establishment of plants, may account for the considerably less than complete coverage.

The summits of the mountains in this area have been more resistant to wind and water erosion than the lower slopes and typically feature fortress-like crowns surrounded by columnar jointed cliffs. Within these "fortresses" are found an aggregation of plants not commonly seen elsewhere in the Bofecillos. Four individuals of the Fragrant Ash (*Fraxinus cuspidata*), typically a shrub or small bush, were sighted, along with another shrub *Bouvardia ternifolia*, distinguished by its red funnelform flowers and its whorled leaves. *Eupatorium wrightii*, *Eupatorium solidaginifolium*, *Penstemon havardii*, and *Bernardia obovata* were also collected from the summit areas. These species are common inhabitants of canyons or mountains in the Trans-Pecos. The grass cover, though scant, is made up of those species encountered on the slopes. More widespread taxa also frequent the summits, including Granjeno (*Celtis pallida*), *Forestiera angustifolia*, Guayacan (*Porlieria angustifolia*), Mormon Tea (*Ephedra aspera*), and Resin Bush.

THE ALLUVIAL-GRAVEL ASSOCIATION

The level terrain, which characterizes the Alluvial Gravel Association, surrounds the bases of the scattered peaks forming a continuum within the Bofecillos. Here, the impact of grazing on the vegetation is most apparent. A transect site typifying this association showed a grass cover of only 4.38%, composed exclusively of Fluffgrass (*Erioneuron pulchellum*). The abundance of Creosote was reflected in a relative dominance value of 43.7%. The characteristic spacing of this desert shrub accounts for the scanty total plant coverage of 59.26% (Table 2; Fig. 2). Considerable areas within the alluvial gravels were dominated by *Acacia neovernicosa*, another invading shrub of disturbed grasslands, along with Creosote. Transect data obtained from a relatively undisturbed site indicated a marked increase in species diversity, particularly among the grasses (Table 8; Fib. 8). Dominant species include Black Grama, Arizona Cottontop, and Spidergrass (*Aristida ternipes*). Numerous other grasses were less frequently encountered. Lechuguilla and Bluntscale Bahia were overwhelmingly the dominant herbs, while the other species recorded comprised a very minor portion of the cover. Resin Bush, *Acacia angustissima* var. *chisosiana*, Catclaw Acacia, and Engelmann Prickly Pear made up the shrub component. Notwithstanding a considerable change in the diversity of species present, the plant cover remained sparse with only a 52.96% Total Raw Coverage.

The Alluvial Gravel Association was frequently dissected by minor drainages. In the vicinity of such streams, populations of Tarbush, Wolfberry (*Lycium berlandieri*), Guayacan, and Mesquite were observed, in addition to the species mentioned above. A greater quantity of available water may account for this increased diversity.

Although a few individuals of *Juniperus pinchotii* were observed infrequently throughout the Alluvial Gravel Association, no populations of this Juniper have been found in the mountainous portion of the Bofecillos.

THE MESA ASSOCIATION

The southern extent of the Bofecillos Mountains features a series of mesas, the most prominent being

Upper and Lower Wylie Mesa. Access to this area is by a rather difficult, ungraded jeep trail. The level terrain found on the mesa tops is in sharp contrast to the sheer slopes that form the adjacent canyon walls. The absence of any significant drainages or running springs results in a scarcity of water here. Although water at one time was pumped into the area, the supply is no longer available, as indicated by numerous broken pipes and empty stock tanks. Apparently the isolation, in addition to the absence of water, has rendered the mesas impractical for grazing purposes. That portions of Upper Wylie Mesa had previously been heavily grazed is shown by the local dominance of *Acacia neovernicosa,* Creosote, and Ocotillo. However, data from a quadrat transect run in a less-disturbed area revealed the highest percentage of cover with a total raw coverage of 80.76% (Table 6; Fig. 6). Grasses occupied 28.8% of this coverage. A high diversity of grasses was recorded, the most common species being Side-Oats Grama, Tanglehead, Slim Tridens, and Black Grama. Lechuguilla was abundant, showing a relative dominance of 32.07%. Cat's Claw Mimosa, Sotol, and Broomweed also were common at this transect site. Lower Wylie Mesa appeared to be the least disturbed of all the areas encountered in this survey. No transect data from this portion of the mesa were obtained. However, a noticeably lower frequency of invading shrubs such as Resin Bush *Acacia neovernicosa,* Whitebrush (*Aloysia gratissima*), Engelmann Prickly Pear, and Creosote was observed. Instead, an even distribution of Sotol, Ocotillo, Lechuguilla, and a considerable diversity of grass species was found. The vegetation of Lower Wylie Mesa most closely approaches a climax situation for this plant association. The isolated mesa top, with its level terrain and limited water supply, provides a combination of environmental factors that allows for a unique vegetational composition. Further quantitative sampling may prove helpful in determining the extent of this association's uniqueness within the Bofecillos.

THE RIPARIAN ASSOCIATION

The network of minor drainages that finger through the alluvial gravels merges at various points, thus forming the head of the major canyons. Although no perennial streams run here, existence of an increased supply of water is shown in the dense vegetation that borders these streambeds. Water-loving species such as Apache Plume, Desert Willow (*Chilopsis linearis*), *Brickellia laciniata,* Granjeno, Sugar Hackberry (*Celtis laevigata*), and Burrobrush are scattered throughout the streambeds. Dense growths of Catclaw Acacia, Guayacan, Mesquite, and Saltbush (*Atriplex camescens*) line the banks. *Eupatorium greggii,* Fetid Gourd (*Cucurbita foetidissima*), Chisos Poppy (*Argemone chisosensis*), and *Gaura boquillensis* are also found infrequently. Being restricted to the courses of the drainages, the Riparian Association is delineated by microtopographic features that are measured in terms of meters rather than larger units.

THE CANYON ASSOCIATION

The following discussion of the Canyon Association is based on collections and observations made from the head of Tapado Canyon (Fig. 9). Springs scattered throughout this canyon are a perennial water source. Around such moist habitats, Fragrant Flatsedge (*Cyperus odoratus*), Jointed Rush (*Juncus nodosus*), Stinkgrass (*Eragrostis cilianensis*), Spike Dropseed (*Sporobolus contractus*), Water Bentgrass (*Agrostis semiverticillata*), Junglerice (*Echinochloa colonum*), Waterhyssop (*Bacopa monnieri*), and Cardinal Flower (*Lobelia cardinalis*) flourish. Draping the canyon walls and trees are vines: Canyon Grape (*Vitis arizonica*), Poison Ivy (*Rhus toxicodendron*), and Swallowwort (*Cynanchum unifarium*). The presence of Tree Tobacco (*Nicotiana glauca*) and Salt Cedar (*Tamarix aphylla*) represents a southern influence, for these species are abundant along the banks of the Rio Grande. Shrubs not commonly found outside the canyons include Poreleaf (*Porophyllum scoparium*), Esperanza (*Tecoma stans*), Agarita (*Berberis trifoliolata*), *Prunus havardii*, Evergreen Sumac (*Rhus virens*), and Mexican Buckeye (*Ungnadia speciosa*). Portions of Tapado Canyon are closed, with high, steep walls that provide a degree of protection from the harsh environmental elements. These areas nurture the growth of trees such as Soapberry (*Sapindus saponaria*), Fresno, Southwestern Black Willow, Little Walnut (*Juglans microcarpa*), and Chapa, many of which attain considerable height. One individual of Mountain Mulberry (*Morus microphylla*) is located a short distance south of Oso Spring in Tapado Canyon. As the scientific name implies, Mountain Mulberry is recognized by its small leaves which are scabrous on both surfaces. Mountain Mulberry is infrequently found at any one locality. However, the distribution of this species is so extensive, involving the western two-thirds of Texas, Arizona, and Mexico, that it can hardly be considered rare. In general, the vegetation of this canyon is consistent with that found in the canyons included in the Colorado Canyon Study Area. Such a consistency is to be expected, for the canyons alone provide the moist oases necessary to insure the continued survival of many of these relic populations.

RARE PLANTS

Although not encountered on this survey, two rare Cruciferae are known from the eastern extent of the Bofecillos Mountains. Both early spring annuals, *Thalypodium tenue* is endemic to the bed of Fresno Creek, while *Sisymbrium purpusii* has been collected among boulders or cliffs in Fresno Canyon, particularly in the vicinity of the Smith house. The range of *Sisymbrium purpusii* extends into northern Mexico and Arizona.

CONCLUSION

A basic continuity was found between the vegetation of the Bofecillos Mountains and the other study areas on the Big Bend Ranch. A major distinction was seen in the degree to which the land had been disturbed. The fact that much of the Bofecillos Range is being used for grazing purposes has resulted in a tremendous impact on the plant life. Considerable portions of this range exhibit a marked decrease in grass diversity, as well as an overwhelming abundance of Creosote and *Acacia neovernicosa.* In the canyons and among rock crevices of the summits lies the potential for unique floristic elements. These areas, particularly within the western extent of the Bofecillos where access is limited, require further sampling both qualitatively and quantitatively in order to facilitate a more complete evaluation of the vegetation of the Bofecillos Mountains.

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APPENDIX 1

Localities for transects presented in Tables 1-8.

Table 1–North-facing slope about 1.6 km. East of Javalena Camp and about 1.6 km sout by southwest of Ojo Mexicana. (Sauceda Ranch 7.5-minute gradrangle)

Table 2–About .4 km west of Papalote Llano, just east of jeep trail leading to Javalena Camp. (Sauceda Ranch 7.5-minute quadrangle)

Table 3–West facing slope of No. 4890, just south of Agua Adentro Mountain. (Agua Adentro Mountain 7.5-minute quadrangle)

Table 4–North facing slope of No. 4890, just south of Agua Adentro Mountain. (Agua Adentro Mountain 7.5-minute quadrangle)

Table 5–Southwest facing slope, about 2 km southeast of Oso Mountain, east of jeep trail leading to Wylie Mesa. (Agua Adentro Mountain 7.5-minute quadrangle)

Table 6–About 1.2 km southwest of corral on Upper Wylie Mesa, just west of jeep trail in vicinity of stock tank. (Agua Adentro Mountain 7.5-minute quadrangle)

Table 7–Southwest facing slope about 1.6 km northeast of Oso Mountain and 2 km east of Agua Adentro Mountain. (Agua Adentro Mountain 7.5-minute quadrangle)

Table 8–About .8 km southwest of county road and about .5 km southeast of Papalote Escondido. (Sauceda Ranch 7.5-minute quadrangle)

APPENDIX 2

Explanation of Symbols Used in Tables

Q = Total quadrats in which species occurred

RFi = Raw Frequency = Precent quadrats in which species occurred

RFii = Relative Frequency = $\frac{\text{Q of species}}{\text{Total Q}}$

RDi = Relative Density = $\frac{\text{Total individuals of species}}{\text{Total individuals of all species}}$

TI = Total Individuals

RC = Raw Cover = $\frac{\text{Total area covered by species}}{\text{Total area sampled}}$

RDii = Relative Dominance = $\frac{\text{Area covered by species}}{\text{Area covered by all species}}$

TA = Index to the total area covered by species, expressed by a percentage

FIGURE 1

The Slope Association – site for Quadrat Transect 15.

TABLE 1
Quadrat Transect 15

	Q	RFi	RFii	TI	RDi	RC	RDii	TA
GRASSES								
Aristida wrightii	1	1.67	.53	2	.52	.08	.13	5
Bothriochla saccharoides	2	3.33	1.05	2	.52	.17	.27	10
Bouteloua curtipendula	54	90.00	28.42	198	51.30	26.10	41.74	1566
Bouteloua eriopoda	2	3.33	1.05	6	1.55	.92	1.74	55
Bouteloua ramosa	1	1.67	.53	4	1.04	.33	.53	20
Leptochloa dubia	9	15.00	4.74	20	5.18	2.00	3.20	120
Setaria leucopila	1	1.67	.53	1	.26	.08	.12	5
Trichachne californica	2	3.33	1.05	4	1.04	.42	.67	25
HERBS								
Artemisia ludoviciana	6	10.00	3.16	6	1.55	1.30	2.08	78
Bahia pedata	10	16.67	5.26	13	3.37	2.12	3.38	127
Erigeron modestus	14	23.33	7.37	17	4.40	1.97	3.14	118
Hedeoma drummondii	5	8.33	2.63	5	1.30	.37	.59	22
Iva ambrosiifolia	1	1.67	.53	1	.26	.17	.27	10
Maurandya antirrhiniflora	1	1.67	.53	1	.26	.08	.13	5
Notholaena sinuata	1	1.67	.53	1	.26	.17	.27	10
Notholaena standleya	2	3.33	1.05	2	.52	.25	.40	15
Pectis papposa	1	1.67	.53	1	.26	.02	.03	1
Perezia wrightii	7	11.67	3.68	14	3.63	2.83	4.53	170
Phacelia spp.	1	1.67	.53	1	.26	.17	.27	10
Ruellia spp.	1	1.67	.53	1	.26	.08	.13	5
Selaginella wrightii	7	11.67	3.68	14	3.63	2.83	4.53	170
Verbena neomexicana	8	13.33	4.21	8	2.07	.48	.77	29
SHRUBS								
Aloysia wrightii	7	14.00	4.52	7	1.92	5.20	6.57	260
Dasylirion texanum	2	3.33	1.05	2	.52	1.83	2.93	110
Ephedra aspera	2	3.33	1.05	2	.52	.58	.93	35
Forestiera angustifolia	1	2.00	.65	1	.27	2.00	2.53	100
Gymnosperma glutinosum	5	10.00	3.23	7	1.92	.26	.33	13
Nolina erumpens	1	1.67	.53	1	.26	.67	1.07	40
Opuntia phaeacantha var. *discata*	8	16.00	5.16	8	2.19	9.80	12.38	490
Prunus havardii	1	2.00	.65	1	.27	.70	.88	35
Viguiera stenoloba	12	24.00	7.74	19	5.21	8.26	10.44	413
Xanthocephalum microcephalum	6	10.00	3.16	8	2.07	.93	1.49	56
TOTALS	155		100.08%	365	99.98%	73.17%	100.01%	4128%

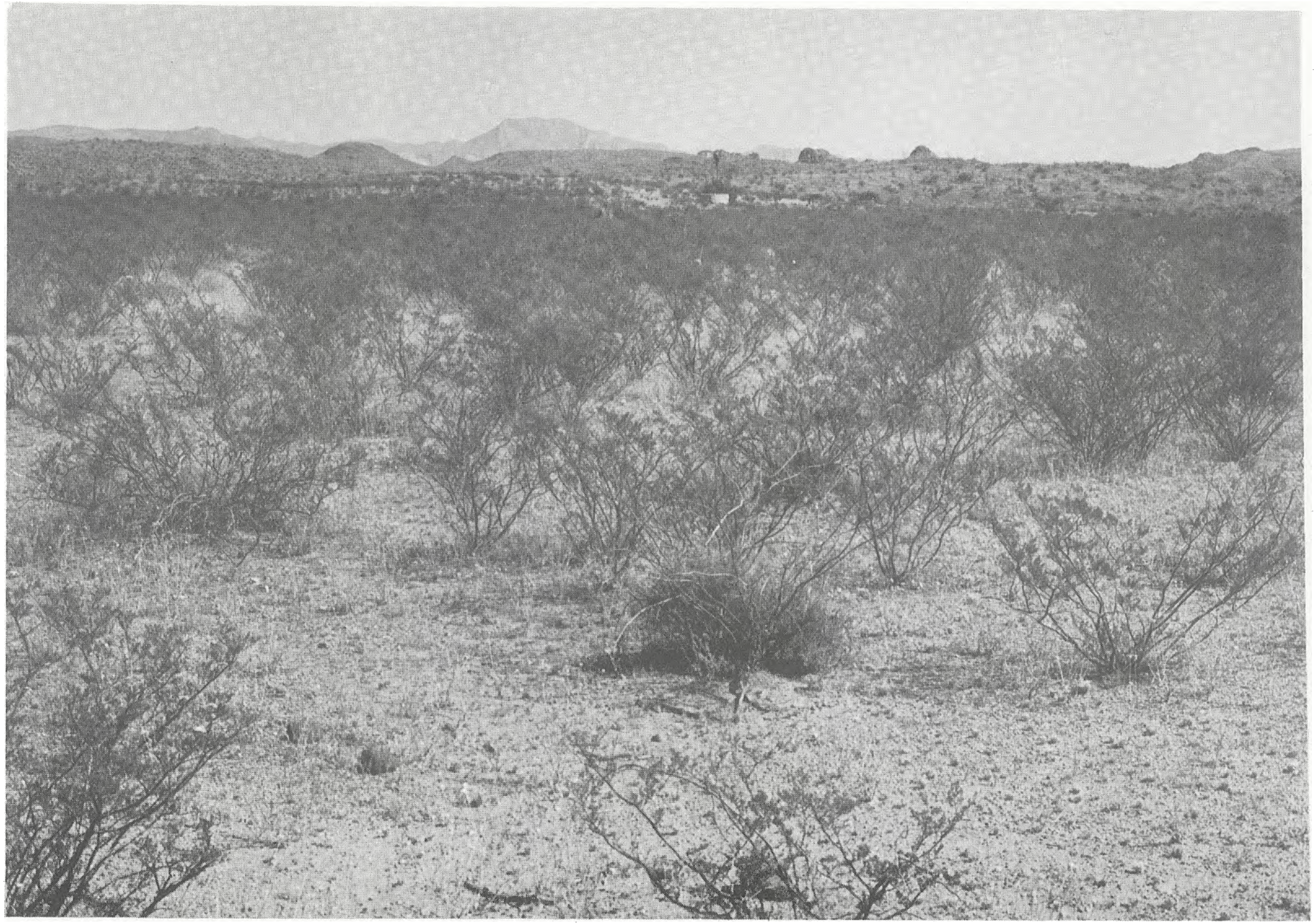

FIGURE 2
The Alluvial Gravel Association – site for Quadrat Transect 16.

TABLE 2
Quadrat Transect 16

	Q	RFi	RFii	TI	RDi	RC	RDii	TA
GRASSES								
Erioneuron pulchellum	28	56	19.18	91	26.53	4.38	7.39	219
HERBS								
Bahia absinthifolia	5	10	3.42	11	3.21	.88	1.48	44
Bahia pedata	12	24	8.22	19	5.54	2.54	4.29	127
Baileya multriadiata	32	64	21.92	112	32.65	13.88	23.42	694
Cassia bauhinioides	1	2	.68	1	.29	.10	.17	5
Dyssodia pentachaeta	4	8	2.74	5	1.46	.40	.67	20
Gilia rigidula	24	48	16.44	50	14.58	3.46	5.84	173
Hedeoma drummondii	2	4	1.37	9	2.62	.40	.67	20
Iva ambrosiifolia	3	6	2.05	3	.87	.60	1.01	30
Machaeranthera scabrella	2	4	1.37	2	.58	.20	.32	10
Opuntia leptocaulis	1	2	.68	1	.29	.30	1.51	15
Pectis papposa	3	6	2.05	5	1.46	.32	.54	16
Verbena neomexicana	6	12	4.11	9	2.62	2.72	4.59	136
SHRUBS								
Fouquieria splendens	1	2	.68	1	.29	1.50	2.53	75
Larrea tridentata	18	36	12.33	18	5.25	25.90	43.70	1295
Opuntia phaeacantha var. *discata*	1	2	.68	2	.58	1.00	1.69	50
Parthenium incanum	3	6	2.05	4	1.17	.68	1.15	34
TOTALS	**146**		**99.97%**	**343**	**99.99%**	**59.26%**	**99.99%**	**2963%**

FIGURE 3
The Slope Association – site for Quadrat Transect 17.

TABLE 3
Quadrat Transect 17

	Q	RFi	RFii	TI	RDi	RC	RDii	TA
GRASSES								
Aristida adscensionis	10	20	7.09	23	7.32	1.28	2.19	64
Aristida wrightii	1	2	.71	1	.32	.10	.17	5
Bothriochloa saccharoides	1	2	.71	1	.32	.20	.34	10
Bouteloua curtipendula	34	68	24.11	116	36.94	15.76	26.91	788
Bouteloua eriopoda	3	6	2.13	11	3.50	1.40	2.39	70
Bouteloua ramosa	5	10	3.55	14	4.46	1.90	3.24	95
Erioneuron pulchellum	4	8	2.84	7	2.23	.90	1.54	45
Scleropogon brevifolius	1	2	.71	2	.64	.10	.17	5
Setaria leucopila	2	4	1.42	4	1.27	.30	.51	15
Trichachne californica	2	4	1.42	4	1.27	.70	1.19	35
HERBS								
Abutilon parvulum	1	2	.71	1	.32	.20	.32	10
Bahia pedata	2	4	1.42	2	.64	.20	.34	10
Baileya multiradiata	1	2	.71	3	.95	.20	.34	10
Croton pottsii	5	10	3.55	8	2.55	1.04	1.78	52
Euphorbia cinerascens	5	10	3.55	6	1.91	.62	1.06	31
Gaura spp.	1	2	.71	1	.32	.20	.34	10
Hedeoma drummondii	3	6	2.13	6	1.91	.22	.37	31
Nolina erumpens	1	2	.71	1	.32	.20	.34	10
Polygala spp.	1	2	.71	11	3.50	.20	.34	10
Talinopsis frutescens	4	8	2.84	4	1.27	.56	.96	28
Tragia ramosa	2	4	1.42	2	.64	.70	1.19	35
Verbena neomexicana	4	8	2.84	11	3.50	.54	.92	27
SHRUBS								
Acacia greggii	1	2	.71	1	.32	.70	1.19	35
Acacia neovernicosa	1	2	.71	1	.32	.06	.10	3
Agave lecheguilla	1	2	.71	1	.32	.40	.68	20
Aloysia wrightii	5	10	3.55	5	1.59	4.90	8.37	245
Cassia wislizeni	1	2	.71	1	.32	2.00	3.41	100
Dasylirion texanum	2	4	1.42	2	.64	2.30	3.93	115
Forestiera angustifolia	1	2	.71	1	.32	.70	1.19	35
Fouquieria splendens	2	4	1.42	2	.64	.40	.68	20
Gymnosperma glutinosum	13	26	9.22	43	13.69	3.28	5.60	164
Opuntia phaeacantha var. *discata*	3	6	2.13	3	.95	1.60	2.73	80
Parthenium incanum	5	10	3.55	8	2.55	3.70	6.32	185
Prosopis glandulosa	1	2	.71	1	.32	2.00	3.41	100
Viguiera stenoloba	11	22	7.80	14	4.45	9.30	15.20	465
Xanthocephalum microcephalum	1	2	.71	2	.64	.10	.17	5
TOTALS	**141**		**100.05%**	**314**	**99.99%**	**58.96%**	**99.95%**	**2948%**

FIGURE 4
The Slope Association – site for Quadrat Transect 18.

TABLE 4
Quadrant Transect 18

	Q	RFi	RFii	TI	RDi	RC	RDii	TA
GRASSES								
Aristida adscensionis	1	2	0.59	3	.82	.20	.25	10
Bothriochloa saccharoides	1	2	0.59	2	.55	.80	1.01	40
Bouteloua curtipendula	36	72	21.30	149	40.82	19.44	24.56	972
Bouteloua eriopoda	2	4	1.18	13	3.56	2.00	2.53	100
Bouteloua ramosa	2	4	1.18	3	.82	.60	.76	30
Erioneuron grandiflorum	6	12	3.55	12	3.29	1.20	1.52	60
Hilaria mutica	1	2	0.59	3	.82	.70	.88	35
Leptochloa dubia	4	8	2.37	15	4.11	2.70	3.41	135
Setaria leucopila	8	16	4.73	23	6.30	2.30	2.91	115
Stipa eminens	1	2	0.59	1	.27	.10	.13	5
Trichachne californica	5	10	2.96	9	2.47	1.70	2.15	85
Tridens muticus	1	2	0.59	1	.27	.30	.38	15
HERBS								
Croton pottsii	1	2	0.59	3	.82	.40	.50	20
Dalea wrightii	1	2	0.59	1	.27	.50	.63	25
Dyssodia pentachaeta	1	2	0.59	1	.27	.10	.13	5
Hedeoma drummondii	7	14	4.14	13	3.56	.42	.53	21
Lesquerella fendleri	1	2	0.59	3	.82	.10	.13	5
Leucelene ericoides	5	10	2.96	10	2.74	1.16	1.47	58
Menodora decemfida	1	2	0.59	1	.27	.30	.38	15
Notholaena standleya	1	2	0.59	1	.27	.10	.13	5
Polygala spp.	2	4	1.18	4	1.10	.12	.15	6
Selaginella wrightii	2	4	1.18	2	.55	.70	.88	35
SHRUBS								
Acacia greggii	1	1.67	0.59	1	.26	1.58	2.53	95
Aloysia wrightii	7	11.67	4.14	7	1.81	2.58	4.13	155
Cassia wislizeni	1	1.67	0.59	1	.26	1.67	2.66	100
Forestiera angustifolia	1	1.67	0.59	1	.26	.33	.53	20
Gymnosperma glutinosum	20	33.33	11.83	33	8.55	2.62	4.18	157
Nolina erumpens	1	2	0.59	1	.27	.10	.13	5
Opuntia phaeacantha var. *discata*	1	1.67	0.59	1	.26	.58	.93	35
Parthenium incanum	12	24	7.10	14	3.84	10.50	14.38	525
Viguiera stenoloba	17	28.33	10.06	20	5.18	10.78	14.46	539
Xanthocephalum microcephalum	18	36	10.65	34	9.32	6.48	8.19	324
TOTALS	**169**		**99.95%**	**386**	**100.02%**	**73.16%**	**99.98%**	**3651%**

FIGURE 5

The Slope Association – site for Quadrat Transect 19.

TABLE 5
Quadrat Transect 19

	Q	RFi	RFii	TI	RDi	RC	RDii	TA
GRASSES								
Aristida glauca	12	4	1.09	5	1.47	.40	0.70	20
Aristida ternipes	8	16	4.37	12	3.54	2.20	3.84	110
Bouteloua curtipendula	14	28	7.65	29	8.55	4.60	8.04	230
Bouteloua ramosa	10	20	5.46	13	3.83	3.54	6.18	177
Erioneuron pulchellum	7	14	3.82	10	2.95	.96	1.68	48
Hilaria belangeri	8	16	4.37	75	22.12	5.20	9.08	260
Hilaria mutica	1	2	.55	3	0.18	.70	1.22	35
Panicum hallii	2	4	1.09	5	1.47	.40	0.70	20
Setaria leucopila	1	2	.55	3	0.88	.40	0.70	20
Tridens muticus	1	2	.55	1	0.30	.30	0.52	15
HERBS								
Abutilon parvulum	1	2	.55	1	0.30	.10	0.14	5
Allionia incarnata	4	8	2.19	5	1.47	1.20	2.10	60
Bahia absinthifolia	2	4	1.09	3	0.88	.16	0.28	8
Baileya multiradiata	6	12	3.28	7	2.06	.42	0.73	21
Cevallia sinuata	1	2	.55	1	0.30	.70	1.22	35
Chamaesaracha coniodes	1	2	.55	1	0.30	.10	0.17	5
Croton pottsii	8	16	4.37	21	6.19	1.76	3.07	88
Dalea wrightii	1	2	.55	1	0.29	.06	0.10	3
Echinocereus spp.	2	4	1.09	2	0.59	.50	0.87	25
Eupatorium solidaginifolium	1	2	.55	1	0.30	.50	0.87	25
Euphorbia spp.	1	2	.55	1	0.30	.30	0.52	15
Evolvulus alsinoides	1	2	.55	1	0.30	.30	0.52	15
Hedeoma drummondii	1	2	.55	2	0.59	.10	0.17	5
Hibiscus coulteri	1	2	.55	1	0.30	.06	0.10	3
Iva ambrosifolia	1	2	.55	1	0.30	.10	0.17	5
Machaeranthera scabrella	2	4	1.09	2	0.59	.40	0.70	20
Menodora decemfida	1	2	.55	1	0.30	.30	0.52	15
Menodora scabra	1	2	.55	1	0.30	.06	0.10	3
Pectis papposa	1	2	.55	3	0.88	.40	0.70	20
Polygala spp.	1	2	.55	3	0.88	.10	0.17	5
Ruellia parryi	4	8	2.19	5	1.47	.80	1.40	40
Thamnosma texana	7	14	3.82	13	3.83	.44	0.77	22
Verbena neomexicana	42	82	22.95	66	19.47	3.66	6.39	183
SHRUBS								
Agave lecheguilla	3	6	1.64	4	1.18	1.40	2.44	70
Aloysia wrightii	2	4	1.09	2	0.59	2.40	3.19	120
Coldenia greggii	1	2	.55	1	0.30	.80	1.40	40
Dasylirion texanum	2	4	1.09	2	0.59	.80	1.40	40
Flourensia cernua	2	4	1.09	2	0.59	1.10	1.92	55
Forestiera angustifolia	1	2	.55	1	0.30	.70	1.22	35
Fouquieria splendens	10	20	5.46	10	2.95	7.60	13.28	380
Larrea tridentata	1	2	.55	1	0.30	.50	0.87	25
Mimosa biuncifera	1	2	.55	1	0.30	.50	0.87	25
Parthenium incanum	1	2	.55	1	0.30	.10	0.87	5
Prosopis glandulosa	1	2	.55	1	0.30	1.20	2.10	60
Trixis californica	1	2	.55	2	0.59	.30	0.52	15
Viguiera stenoloba	12	24	6.56	12	3.54	8.62	15.06	431
TOTALS	183		100.05%	33.9	100.02%	57.24%	99.91%	2862%

FIGURE 6

The Mesa Association -- site for Quadrat Transect 20.

TABLE 6
Quadrat Transect 20

	Q	RFi	RFii	TI	RDi	RC	RDii	TA
GRASSES								
Aristida glauca	1	2	.65	1	.32	.30	.37	15
Bothriochloa saccharoides	7	14	4.55	9	2.84	1.70	2.10	85
Bouteloua curtipendula	23	46	14.94	60	18.93	9.74	12.06	487
Bouteloua eriopoda	6	12	3.90	17	5.36	2.70	3.34	135
Bouteloua hirsuta	2	4	1.30	4	1.26	1.20	1.49	60
Bouteloua ramosa	1	2	.65	2	.63	.20	.25	10
Erioneuron pilosum	1	2	.65	1	.32	.30	.37	15
Erioneuron pulchellum	2	4	1.30	2	.63	.40	.50	20
Heteropogon contortus	12	24	7.79	24	7.57	6.00	7.43	300
Setaria leucopila	1	2	.65	1	.32	.10	.12	5
Tridens muticus	15	30	9.74	42	13.25	6.16	7.63	308
HERBS								
Chamaesaracha coniodes	1	2	.65	1	.32	.06	.07	3
Chamaesyce cinerascens	2	4	1.30	2	.63	.16	.20	8
Croton pottsii	1	2	.65	1	.32	.06	.07	3
Dalea frutescens	1	2	.65	1	.32	.20	.25	10
Desmanthus cooleyi	3	6	1.95	5	1.58	1.50	1.86	75
Dyssodia pentachaeta	1	2	.65	2	.63	.10	.12	5
Hedeoma drummondii	1	2	.65	2	.63	.06	.07	3
Mammillaria spp.	1	2	.65	1	.32	.10	.12	5
Pectis papposa	2	4	1.30	4	1.26	.26	.32	13
Ruellia parryi	2	4	1.30	2	.63	.40	.50	20
Sida filicaulis	3	6	1.95	3	.95	.40	.50	20
Thamnosma texana	2	4	1.30	7	2.21	1.30	1.61	65
SHRUBS								
Acacia greggii	1	2	.65	1	.32	.40	.50	20
Acacia neovernicosa	1	2	.65	1	.32	.40	.50	20
Agave lecheguilla	32	64	20.78	87	27.44	25.90	32.07	1295
Aloysia wrightii	2	4	1.30	2	.63	.80	.99	40
Cassia wislizenii	1	2	.65	1	.32	1.20	1.49	60
Dasylirion texanum	2	4	1.30	2	.63	4.00	4.95	200
Gymnosperma glutinosum	2	4	1.30	2	.63	.10	.12	5
Mimosa biuncifera	8	16	5.19	8	2.52	7.50	9.29	375
Parthenium incanum	1	2	.65	1	.32	2.00	2.48	100
Opuntia phaeacantha var. *discata*	2	4	1.30	2	.63	.70	.87	35
Viguiera stenoloba	3	6	1.95	3	.95	1.50	1.85	75
Xanthocephalum microcephalum	8	16	5.19	13	4.10	2.86	3.54	143
TOTALS	154		100.03%	317	100.04%	80.76%	100.00%	4038%

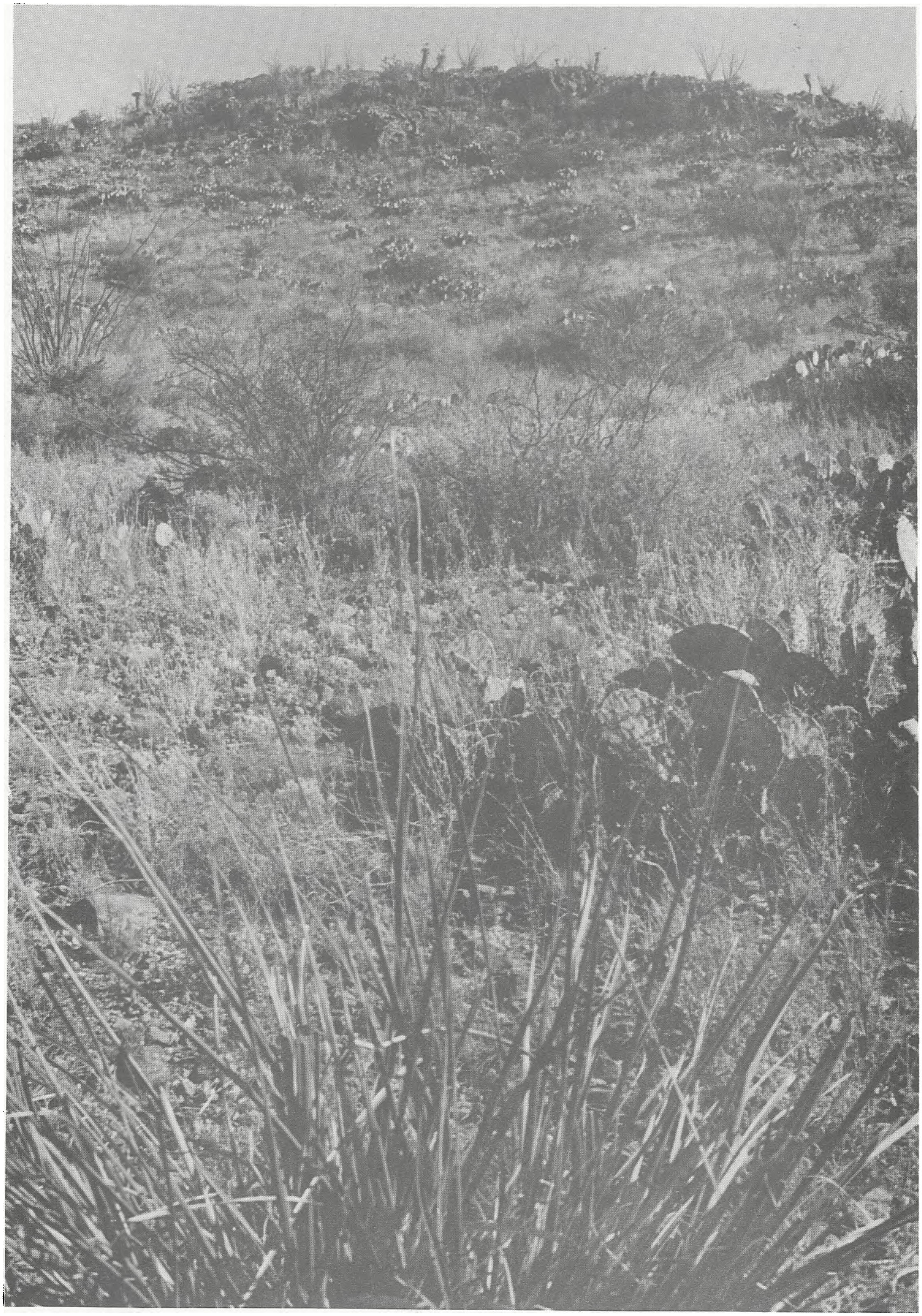

FIGURE 7

The Slope Association – site for Quadrat Transect 21.

TABLE 7
Quadrat Transect 21

	Q	RFi	RFii	TI	RDi	RC	RDii	TA
GRASSES								
Aristida glauca	9	18	4.64	18	4.12	1.80	2.53	90
Aristida ternipes	7	14	3.61	9	2.06	2.20	3.09	110
Bouteloua curtipendula	14	28	7.22	36	8.24	4.90	6.88	245
Bouteloua eriopoda	18	36	9.28	58	13.27	8.30	11.66	415
Erioneuron pulchellum	12	24	6.19	22	5.03	2.46	3.46	123
Heteropogon contortus	5	10	2.58	9	2.06	1.60	2.25	80
Muhlenbergia monticola	1	2	.52	3	.69	1.00	1.40	50
Trichachne californica	3	6	1.55	5	1.14	.80	1.12	40
Tridens muticus	1	2	.52	4	.91	.40	.56	20
HERBS								
Allionia incarnata	1	2	.52	1	.23	.20	.28	10
Bahia pedata	21	42	10.82	76	17,39	7.52	10.56	376
Baileya multiradiata	12	24	6.19	18	4.12	3.10	4.35	155
Carlowrightia linearifolia	1	2	.52	1	.23	.30	.42	15
Croton pottsii	13	26	6.70	29	6.64	2.54	3.57	127
Dalea frutescens	1	2	.52	1	.23	.20	.28	10
Echinocereus spp.	1	2	.52	1	.23	.20	.28	10
Eriogonum abertianum	1	2	.52	1	.23	.10	.14	5
Evolvulus alsinoides	1	2	.52	4	.91	.40	.56	20
Hedeoma drummondii	2	4	1.03	14	3.20	.40	.56	20
Hibiscus denudatus	1	2	.52	1	.23	.10	.14	5
Iva ambrosiifolia	12	24	6.19	35	8.01	4.36	6.12	218
Machaeranthera scabrella	16	32	8.25	24	5.49	1.78	2.50	89
Polygala spp.	1	2	.52	1	.23	.10	.14	5
Verbena neomexicana	9	18	4.64	21	4.81	1.00	1.40	50
SHRUBS								
Acacia greggii	5	10	2.58	5	1.14	3.10	4.35	155
Agave lecheguilla	8	16	4.12	22	5.03	8.40	11.80	420
Aloysia wrightii	1	2	.52	1	.23	1.20	1.69	60
Cassia wislizenii	2	4	1.03	2	.46	4.00	5.62	200
Desmanthus cooleyi	1	2	.52	1	.23	.20	.28	10
Fouquieria splendens	2	4	1.03	2	.46	2.00	2.81	100
Opuntia imbricata	1	2	.52	1	.23	1.20	1.68	60
Opuntia phaeacantha var. *discata*	9	18	4.64	9	2.06	4.24	5.96	212
Parthenium incanum	2	4	1.03	2	.46	1.10	1.54	55
TOTALS	194	388%	100.08%	437	100.00%	71.20%	99.98%	3560%

FIGURE 8

The Alluvial Gravel Association – site for Quadrat Transect 22.

TABLE 8
Quadrat Transect 22

	Q	RFi	RFii	TI	RDi	RC	RDii	TA
GRASSES								
Aristida glauca	2	4	1.29	2	0.75	.60	0.95	30
Aristida ternipes	8	16	5.16	9	3.40	2.10	3.31	105
Bothriochloa saccharoides	3	6	1.93	3	1.13	1.70	2.68	85
Bouteloua curtipendula	4	8	2.58	5	1.89	1.20	1.89	60
Bouteloua eriopoda	8	16	5.16	26	9.81	4.00	6.31	200
Bouteloua hirsuta	2	4	1.29	5	1.89	.08	0.13	4
Erioneuron grandiflorum	4	8	2.58	5	1.89	.46	0.73	23
Erioneuron pulchellum	10	20	6.45	25	9.43	1.84	2.90	92
Heteropogon contortus	1	2	.65	1	0.38	.06	0.09	3
Hilaria mutica	1	2	.65	16	6.04	1.10	1.73	55
Leptochloa dubia	5	10	3.23	6	2.26	1.50	2.37	75
Setaria leucopila	1	2	.65	1	0.38	.30	0.47	15
Trichachne californica	12	24	7.74	20	7.55	3.90	6.15	195
HERBS								
Bahia pedata	27	54	17.42	44	16.60	15.90	25.08	795
Baileya multiradiata	2	4	1.29	2	0.75	.40	0.63	20
Boerhavia coccinea	2	4	1.29	2	0.75	.40	0.63	20
Croton pottsii	2	4	1.29	2	0.75	.20	0.31	10
Dalea frutescens	1	2	.65	1	0.38	.10	0.16	5
Dyssodia pentachaeta	1	2	.65	1	0.38	.10	0.16	5
Eriogonum wrightii	1	2	.65	1	0.38	.10	0.16	5
Iva ambrosiifolia	2	4	1.29	3	1.13	.66	1.04	33
Kuhnia chlorolepis	1	2	.65	1	0.38	.40	0.63	20
Machaeranthera scabrella	13	26	8.39	17	6.41	2.00	3.15	100
Sida filicaulis	2	4	1.29	2	0.75	.40	0.63	20
Sisymbrium linearifolium	1	2	.65	2	0.75	.40	0.63	20
Talinopsis frutescens	2	4	1.29	2	0.75	.50	0.79	25
SHRUBS								
Acacia angustissima var. *chisosiana*	3	6	1.94	3	1.13	1.50	2.37	75
Acacia greggii	2	4	1.29	2	0.75	1.20	1.89	60
Agave lecheguilla	20	40	12.90	44	16.60	15.90	25.08	795
Mimosa biuncifera	1	2	.65	1	0.38	.80	1.26	40
Opuntia imbricata	1	2	.65	1	0.38	.30	0.47	15
Opuntia leptocaulis	1	2	.65	1	0.38	.10	0.16	5
Opuntia phaeacantha var. *discata*	1	2	.65	1	0.38	1.20	1.89	60
Senecio douglasii var. *jamesii*	3	6	1.94	3	1.13	.36	0.57	18
Viguiera stenoloba	5	10	3.23	5	1.89	1.64	2.59	82
TOTALS	155		100.06%	265	99.98%	63.40%	99.99%	3170%

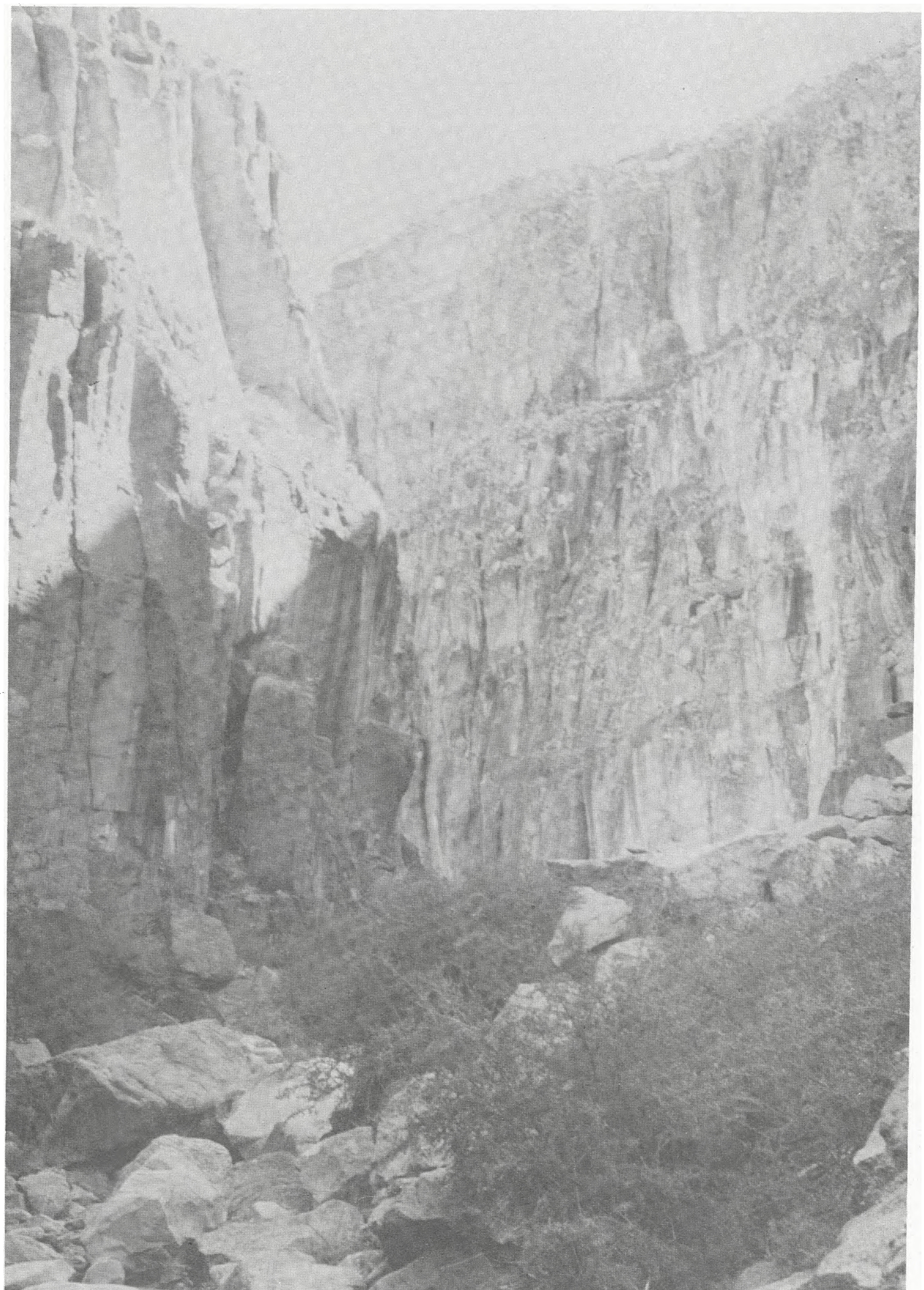

FIGURE 9

The Canyon Association — as represented by Panther Canyon.

BOFECILLOS SPECIES LIST

A — Annual
P — Perennial
I — Introduced
N — Native
* — Rare or Endemic

SELAGINELLACEAE		SPIKE MOSS FAMILY
Selaginella lepidophylla (Hook. & Grev.) Spring	NP	Resurrection Plant Siempre Viva
Selaginella wrightii Hieron.	NP	
POLYPODIACEAE		TRUE FERN FAMILY
Cheilanthes horridula Maxon	NP	Rough Lipfern
Notholaena sinuata (Lag.) var. *sinuata*	NP	Bulb Cloakfern Wavy C.
Notholaena standleyi Maxon	NP	Star Cloakfern
CYPRESSACEAE		CYPRESS FAMILY
Juniperus pinchotii Sudw.		Redberry Juniper
EPHEDRACEAE		EPHEDRA FAMILY
Ephedra aspera Engelm.		Popotillo
POACEAE		GRASS FAMILY
Agrostis semiverticillata (Forsk.) Christ	NP	Water Bent Grass
Aristida adscensionis L.	NA	Six-Weeks Three-awn
Aristida glauca (Nees) Walp	*NP*	Blue Three-awn
Aristida hamulosa Henr.	NP	Hook Three-awn
Aristida ternipes Cav.	NP	Spider Grass
Aristida wrightii Nash	NP	Wright Three-awn
Bothriochloa saccharoides (SW.) Rydb	NP	Silver Beardgrass
Bouteloua barbata Lag.	NA	Six-Weeks Grama
Bouteloua curtipendula (Michx.) Torr.	NP	Sideoats Grama
Bouteloua eriopoda (Torr.) Torr.	NP	Woolyfoot Grama
Bouteloua hirsuta Lag.	NP	Hairy Grama
Bouteloua ramosa Vasey	NP	Chino Grama
Cynodon dactylon (L.) Pers.	IP	Bermuda Grass
Echinochloa colonum (L.) Link.	IA	Junglerice
Enneapogon desvauxii Beauv.	NP	Spike Pappus Grass
Eragrostis cilianensis (All.) E. Mosher.	NA	Stink Grass
Eragrostis neomexicana Vasey	NA	New Mexico Lovegrass
Erioneuron grandiflorum (Vasey) Tateoka	NP	
Erioneuron pulchellum (H.B.K.) Tateoka	NP	Fluffgrass
Heteropogon contortus (L.) Beauv.	NP	Tanglehead
Hilaria belangeri (Steud.) Nash	NP	Curly Mesquite
Hilaria mutica (Buckl.) Benth.	NP	Tabosa
Leptochloa dubia (H.B.K.) Nees	NP	Green Sprangletop
Leptoloma cognatum (Schult.) Chase	NP	Fall Witchgrass
Lycurus phleoides H.B.K.	NP	Wolftail
Muhlenbergia monticola Buckl.	NP	Mesa Muhly
Muhlenbergia porteri Scribn.	NP	Bush Muhly
Panicum hallii Vasey	NP	Halls Panicum
Pappophorum mucronulatum Nees	NP	Whiplash Pappophorum

Paspalum dilatatum Poir.	NP	Dallis Grass
Scleropogon brevifolius Phil.	NP	Burro Grass
Setaria leucopila (Scribn. & Merr.) K. Schum	NP	Bristlegrass
Sporobolus airoides (Torr.) Torr.	NP	Alkali Scaton
Sporobolus contractus Hitchc.	NP	Spike Dropseed
Sporobolus cryptandrus (Torr.) Gray	NP	Sand Dropseed
Stipa eminens Cav.	NP	Southwestern Needlegrass
Tragus berteronianus Schult.	IA	Spike Burgrass
Tridens muticus (Torr.) Nash	NP	Slim Tridens
CYPERACEAE		SEDGE FAMILY
Cyperus spp.		
Cyperus laevigatus L.	NP	Smooth Flatsedge
Cyperus odoratus L.	NP	Fragrant Flatsedge
Eleocharis macrostachya Britt.	NP	Spikerush
Fuirena simplex Vahl.	NP	Western Umbrella Sedge
BROMELIACEAE		PINE-APPLE FAMILY
Hechtia scariosa Smith	NP	Rough False-Agave
JUNCACEAE		RUSH FAMILY
Juncus nodosus L.	NP	Jointed Rush
LILIACEAE		LILY FAMILY
Daslirion leiophyllum Engelm.	NP	Smooth Sotol
Dasylirion texanum Scheele	NP	Texas Sotol
Nolina erumpens (Torr.) Wats.	NP	Beargrass, Basketgrass
Yucca rostrata Engelm.	NP	Beaked Yucca
Yucca thompsoniana Trel.	NP	Thompson Yucca
Yucca torreyi Shafer	NP	Torrey Yucca
AMARYLLIDACEAE		AMARYLLIS FAMILY
Agave lecheguilla Torr.	NP	Lechuguilla
SALICACEAE		WILLOW FAMILY
Populus arizonica Sarg.	NP	Arizona Cottonwood
Salix gooddingii Ball var. *variabilis* Ball	NP	Southwestern Black Willow
JUGLANDACEAE		WALNUT FAMILY
Juglans microcarpa Berland.	NP	Little Walnut
ULMACEAE		ELM FAMILY
Celtis laevigata Willd.	NP	Sugar Hackberry
Celtis pallida Torr.	NP	Granjeno, Spiny Hackberry
MORACEAE		MULBERRY FAMILY
Morus microphylla Buckl.	NP	Mountain Mulberry, Texas Mulberry
URTICACEAE		NETTLE FAMILY
Parietaria floridana Nutt.	NA	**Pellitory**
VISCACEAE		MISTLETOE FAMILY
Phoradendron tomentosum (DC.) Gray	NP	Injerto

ARISTOLOCHIACEAE		BIRTHWORT FAMILY
Aristolochia wrightii Seem.	NP	Wright Dutchmen's Pipe
POLYGONACEAE		KNOTWEED FAMILY
Eriogonum abertianum Torr.	NA	Abert Wildbuckwheat
Eriogonum jamesii Benth.	NP	James Wildbuckweed
Eriogonum rotundifolium Benth.	NA	Roundleaf Wildbuckwheat
Eriogonum tenellum Torr.	NP	Tall Wildbuckwheat
Eriogonum wrightii Torr.	NP	Bastard-Sage, Wright Wildbuckwheat
CHENOPODIACEAE		GOOSE FOOT FAMILY
Atriplex canescens (Pursh) Nutt.	NP	Four Wing Saltbush
Salsola kali L. var. *tenuifolia* Tausch	IA	Russian Thistle, Tumbleweed
AMARANTHACEAE		AMARANTH FAMILY
Amaranthus palmeri Wats.	NA	Careless Weed, Redroot, Palmer Amaranth
Dicraurus leptocladus Hook. f.	NP	
Froelichia arizonica Thornb.	NP	Arizona Snakecotton
Guillerminea densa (Willd.) Moq.	NP	Cotton Flower
Tidestromia lanuginosa (Nutt.) Standl. var. *lanuginosa*	NA	Espanta Vaqueros
NYCTAGINACEAE		FOUR O'CLOCK FAMILY
Acleisanthes longiflora Gray	NP	Herba-De-La-Rabia, Angel Trumpets
Allionia incarnata L.	NP	Hierba De La Hormiga, Umbrella-Wort
Boerhavia coccinea Mill.	NP	Scarlet Spiderling
Cyphomeris gypsophiloides (Mart. & Gal.) Standl.	NP	Red Cyphomeris
Mirabilis diffusa (Heller) Reed	NP	
Selinocarpus angustifoluis Torr.	NP	Narrowleaf Moonpod
PHYTOLACCACEAE		POKEWEED FAMILY
Rivina humilis L.	NP	Bloodberry, Rouge Plant, Pigeon-Berry
PORTULACACEAE		PURSLANE FAMILY
Portulaca mundula I.M. Johnst.	NA	Shaggy Portulaca, Chisme
Portulaca oleracea L.	NA	Verdolaga, Purslane
Talinopsis frutescens Gray		
Talinum aurantiacum Engelm.	NP	Flameflower
RANUNCULACEAE		CROWFOOT FAMILY
Clematis alpina Mill	NP	Alpine Clematis
Clematis drummondii T. & G.	NP	Texas Virgin's Bower, Barbas De Chivato, Old Man's Beard
BERBERIDACEAE		BARBERRY FAMILY
Berberis trifoliolata Moric.	NP	Agarito, Algeritas, Currant-of-Texas
PAPAVERACEAE		POPPY FAMILY
Argemone chisosensis G. B. Ownbey	NP	Chisos Poppy

CRUCIFERAE		MUSTARD FAMILY
Lesquerella purpurea (Gray) Wats.	NP	Rose Bladderpod
Nerisyrenia camporum (Gray) Greene	NP	Mesa Greggia
Sisymbrium lenearifolium (Gray) Pays.	NP	
**Sisymbrium purpusii* (Brandes.) Schulz	NA	
**Thelypodium tenue* Roll.	NA	
CRASSULACEAE		ORPINE FAMILY
Echeveria strictiflora Gray	NP	
Sedum wrightii Gray	NP	Wright Stanecrop
SAXIFRAGACEAE		SAXIFRAGE FAMILY
Fendlera linearis Rehd.	NP	Cliff Fendler Bush
ROSACEAE		ROSE FAMILY
Fallugia paradoxa (Don.) Endl.	NP	Apache Plume
Prunus havardii (W. Wight) W. Wight.	NP	Harvard Plum
LEGUMINOSAE		LEGUME FAMILY
Acacia angustissima (Mill.) O. Ktze. var. *chisosiana* Isely	NP	
Acacia constricta Benth.	NP	Mescat Acacia
Acacia greggii Gray	NP	Cat Claw Acacia
Acacia neovernicosa Isely	NP	
Cassia bauhinioides Gray	NP	Shrubby Senna
Cassia lindheimeriana Scheele	NP	Lindheimer Senna
Cassia wislizenii Gray	NP	Wislizenum Senna
Dalea frutescens Gray	NP	Black Dalea
Dalea lanata Spreng.	NP	Woolly Dalea
Dalea wrightii Gray	NP	Wright Dalea
Desmanthus cooleyi (Eat.) Trel.	NP	James Bundle Flower
Mimosa biuncifera Benth.	NP	Cat's Claw Mimosa
Prosopis glandulosa Torr. var. *glandulosa*	NP	Honey Mesquite
Phaseolus wrightii Gray	NP	Wright Bean
Rhynchosia texana Torr. & Gray	NP	Texas Snoutbean
KRAMERIACEAE		RATANY FAMILY
Krameria grayi Rose & Painter	NP	White Ratany
ZYGOPHYLLACEAE		CALTROP FAMILY
Larrea tridentata (DC.) Cov.	NP	Creosote Bush
Porlieria angustifolia (Engelm.) Gray	NP	Guayacan
Tribulus terrestris L.	IA	Puncturevine, Goathead
RUTACEAE		
Thamnosma texana (Gray) Torr.	NP	Dutchman's Britches, Ruda Del Monte
MALPIGHIACEAE		MALPIGHIA FAMILY
Janusia gracilis Gray	NP	Slender Janusia
POLYGALACEAE		MILKWORT FAMILY
Polygala longa Blake	NP	Narrowleaf Milkwort
Polygala macradenia Gray	NP	Glandleaf Polygala
Polygala scoparioides Chod.	NA	Broom Milkwort

Scientific name	Status	Common name
EUPHORBIACEAE		SPURGE FAMILY
Argythamnia neomexicana Muell. Arg.	NP	Wild Merory
Bernardia obovata I.M. Johnston	NP	Desert Myrtlecroton
Croton pottsii (Kl.) Muell. Arg.	NP	Leather-Weed
Euphorbia antisyphilitica Zucc.	NP	Candelilla
Euphorbia cinerascens Engelm.	NP	
Euphorbia hyssopifolia L.	NA	Hyssopleaf Euphorbia
Jatropha dioica Cerv.	NP	Sangre de Drago, Leather Stem
Phyllanthus polygonoides Spreng.	NP	Leaf-Flower
ANACARDIACEAE		SUMAC FAMILY
Rhus microphylla Engelm.	NP	Correosa, Desert Sumac, Scrub Sumac
Rhus toxicodendrōn L.	NP	Hierda, Poison Ivy, Poison Oak
Rhus virens Gray	NP	Lentisco, Tobacco Sumac, Evergreen Sumac
SAPINDACEAE		SOAP-BERRY FAMILY
Sapindus saponaria L. var. *drummondii* (H. & A.) L. Benson	NP	Jaboncillo
Ungnadia speciosa Endl.	NP	Mexican Buck-eye
RHAMNACEAE		BUCKTHORN FAMILY
Condalia warnockii M. C. Johnst.	NP	
Ziziphus obtusifolia (T. & G.) Gray	NP	Lotebush, Clepe, Gumdrop Tree
VITACEAE		GRAPE FAMILY
Cissus incisa (Nutt.) Des Moul.	NP	Possumgrape, Cow-Itch, Hierba Del Buey
Vitis arizonica Engelm.	NP	Parra Del Monte, Canyon Grape
MALVACEAE		MALLOW FAMILY
Abutilon malacum Wats.	NP	Yellow Abutilon
Abutilon parvulom Gray	NP	Little Leaf Abutilon
Herissantia crispa (L.) Brizicky.	NP	
Hibiscus coulteri Harr.	NP	Desert Rose-Mallow
Hibiscus denudatus Benth.	NP	Paleface Rose-Mallow
Sida filicaulis T. & G.	NP	Spreading Sida
Sida tragiaefolia Gray	NP	
Sphaeralcea angustifolia (Cav.) D. Don	NP	Narrowleaf Globe-Mallow
TAMARICACEAE		TAMARISK FAMILY
Tamarix-aphylla (L.) Karst.	IP	Salt Cedar, French Tamarisk
FOUQUIERIACEAE		OCOTILLO FAMILY
Fouquieria splendens Engelm.	NP	Ocotillo, Coachwhip
KOEBERLINIACEAE		ALLTHORN FAMILY
Koeberlinia spinosa Zucc.	NP	Allthorn, Junco, Crown of Thorns

LOASACEAE		STICK-LEAF FAMILY
Cevallia sinuata Lag.	NP	Stinging Cevallia
Mentzelia multiflora (Nutt.) Gray	NP	Desert Mentzelia
Mentzelia oligosperma Nutt.	NP	Chicken Thief, Stickleaf
CACTACEAE		
Echinocactus Texensis Hopffer	NP	Horse Crippler, Devil's Pincushion
Echinocereus enneacanthus Engelm. var. *stramineus* (Engelm.) L. Benson	NP	Strawberry Cactus
Echinocereus pectinatus (Scheidw.) Engelm. var. *neomexicanus* (Coult.)	NP	Rainbow Cactus
Mammillaria pottsii Scheer	NP	Potts Mammillaria
Neolloydia conoidea (DC.) Britt. & Rose	NP	
Opuntia leptocaulis DC.	NP	Christmas Cactus, Tasajillo
Opuntia phaeacantha Engelm. var. *discata* (Engelm.) L. Benson & Walkington	NP	Engleman Prickly-Pear
Opuntia schotti Engelm.	NP	Clavelling
Opuntia rufida Engelm.	NP	Blind Prickly-Pear
Opuntia violacea Engelm. var. *macrocentra* (Engelm.) L. Benson	NP	Purple Prickly-Pear
ONAGRACEAE		EVENING PRIMROSE FAMILY
Calylophus hartwegii (Benth.) Raven subsp. *hartwegii*	NP	
Gaura sp.		
Oenothera primiveris Gray	NA	Large Yellow Desert Primrose
OLEACEAE		OLIVE FAMILY
Forestiera angustifolia Torr.	NP	Desert Olive, Panalero
Fraxinus cuspidata Torr.	NP	Fragrant Ash, Flowering Ash
Menodora decemfida (Gill) Gray var. *longifolia* Steyerm.	NP	Tenfinger Menodora
Menodora longiflora Gray	NP	Showy Menodora, Twin-Pod
Menodora scabra Gray var. *scabra*	NP	Rough Menodora
APOCYNACEAE		DOG BONE FAMILY
Macrosiphonia macrosiphon (Torr.) Heller	NP	Flor De San Juan, Plateau Rocktrumpet
ASCLEPIADACEAE		MILKWEED FAMILY
Asclepias asperula (Dcne.) Woods. subsp. *asperula*	NP	Milkweed
Cynanchum barbigerum (Scheele) Shinners	NP	Bearded Swallowwort, Thicket Threadvine
Cyanchum unifarium (Scheele) Woods.	NP	Talayote
Sarcostemma torreyi (Gray) Woods.	NP	Soft Twinevine
CONVOLVULACEAE		MORNING GLORY FAMILY
Convolvulus equitans Benth.	NA	
Evolvulus alsinoides L. var. *hirticaulis* Torr.	NP	Ojo do Vibora
POLEMONIACEAE		PHLOX FAMILY
Gilia rigidula Benth. subsp. *rigidula*	NP	Prichleaf Gilia
HYDRO PHYLLACEAE		WATERLEAF FAMILY
Nama havardii Gray	NA	Havard Nama
Nama hispidum Gray	NA	Rough Nama
Phacelia sp.		

BORAGINACEAE		BORAGE FAMILY
Coldenia canescens DC.	NP	Oreja De Perro, Gray Coldenia
Coldenia greggii (T. & G.) Gray	NP	Plume Coldenia
Cryptantha mexicana (Brandeg.) I. M. Johnst.	NA	Mexican Cryptantha
VERBENACEAE		VERBAIN FAMILY
Aloysia gratissima (Gill. & Hook.) Troncoso	NP	Common Bee-Brush, Palo Amarillo
Aloysia wrightii (Gray) Heller	NP	Oreganillo
Lantana macropoda Torr.	NP	Mejorana, Veinyleaf Lantana
Verbena neomexicana (Gray) Small var. *hirtella* Perry	NP	Hillside Vervain
Verbena wrightii Gray	NA	Desert Verbena
LABIATAE		MINT FAMILY
Hedeoma drummondii Benth. var. *drummondii*	NP	Drummond Hedeoma, Mock Penny Royal
Marrubium vulgare L.	IP	Common Horehound, Marrubio
SOLANACEAE		POTATOE FAMILY
Chamaesaracha conoides (Dun.) Britt.	NP	False, Nightshade
Datura wrightii Regel	NA	Indian Apple, Sacred Datura
Lycium berlandieri Dun. var. *parviflorum* (Gray)	NP	Wolfberry
Nicotiana glauca Graham	IP	Tree Tobacco, Mustard Tree
Nicotiana trigonophylla Dunal	NA	Desert Tobacco, Tabaquillo
Physalis hederaefolia Gray var. *puberula* Gray	NP	Heartleaf Groundcherry
Solanum eleagnifolium Cav.	NP	Silverleaf Nightshade, White Horsenettle, Trompillo
SCROPHULARIACEAE		FIGWORT FAMILY
Bacopa monnieri (L.) Wattst.	NP	Coastal Water Hyssop
Castilleja lanata Gray	NP	Indian Paintbrush
Leucophyllum frutescens (Berl.) I. M. Johnst.	NP	Cenizo, Purple Sage
Leucophyllum minus Gray	NP	Big Bend Silverleaf
Maurandya antirrhinifolia Willd.	NP	Snapdragon Vine
Mecardonia vandellioides (H.B.K.) Penn.	NP	
Penstemon baccharifolius Hook.	NP	Charisleaf Penstemon
Penstemon havardii Gray	NP	Harvard Penstemon
BIGNONIACEAE		CARALPA FAMILY
Chilopsis linearis (Cav.) Sweet	NP	Desert Willow, Mimbre
Tecoma stans (L.) Juss. var. *angustata* Rehd.	NP	Trumpet-Flower, Esperanza
MARTYNIACEAE		UNICORN PLANT FAMILY
Proboscidea fragrans (Lindl.) Dcne.	NA	
ACANTHACEAE		ACANTHUS FAMILY
Carlowrightia linearifolia (Torr.) Gray	NP	Heath Carlowrightia
Ruellia spp.		
Ruellia parryi Gray	NP	

RUBIACEAE		MADDER FAMILY
Bouvardia ternifolia (Cav.) Schlecht	NP	Scarlet Bouvardia Trompetilla
Galium microphyllum Gray	NP	Bracted Bedstraw
Hedyotis nigricans (Lam.) Fosb.	NP	Bluets
CUCURBITACEAE		GOURD FAMILY
Apodanthera undulata Gray	NP	Melon-Loco
Cucurbita foetidissima H.B.K.	NP	Calabazilla, Fetid Wild Pumpkin, Buffalo Gourd
CAMPANULACEAE		BLUE BELL FAMILY
Lobelia cardinalis L. var. *pseudosplendens* McVaughn	NP	Cardinal Flower
COMPOSITAE		SUNFLOWER FAMILY
Artemisia ludoviciana Nutt.	NP	Western Mugwort
Aster subulatus Michx.	NA	Hierba del Marrano
Baccharis glutinosa (R. & P.) Pers.	NP	Jara, Seepwillow
Bahia absinthifolia Benth.	NP	Hairyseed Bahia
Bahia pedata Gray	NA	Bluntscale Bahia
Baileya multiradiata Harv. & Gray	NA	Desert Baileya
Bidens leptocephala Sherff	NA	Fewflower Bidens
Brickellia cylindracea Gray & Engelm.	NP	Gravelbar Brickellbush
Brickellia laciniata Gray	NP	Splitleaf Brickellbush
Cirsium texanum Buckl.	NP	Thistle
Conyza canadensis (L.) Cronquist var. *glabratus*	NA	Horse-Weed
Conyza coulteri Gray	NA	Coulter Conyza
Dyssodia acerosa DC.	NP	Prickleleaf Dogweed
Dyssodia pentachaeta (DC.) Robinson	NP	Parralena, Common Dogweed
Erigeron modestus Gray	NP	Plains Fleabane
Eupatorium greggii Gray	NP	Palmleaf Eupatorium
Eupatorium solidaginifolium Gray	NP	Shrubby Eupatorium
Eupatorium wrightii Gray	NP	Wright Eupatorium
Flourensia cernua DC.	NP	Tarbush, Hojase
Gnaphalium wrightii Gray	NA	Wright Cudweed
Gymnosperma glutinosum (Spreng.) Less.	NP	Tatalencho
Helianthus annuus L.	NA	Common Sunflower
Heterotheca fulcrata (Greene) Shinners	NP	Rocky Goldaster
Hymenoclea monogyra T. & G.	NP	Burro-Brush
Iva ambrosiifolia Gray	NA	Rag Sumpweed
Kuhnia chlorolepis Woot & Standl.	NP	Southwest Kunhia
Leucelene ericoides (Torr.) Greene		White Aster, Rose Heath
Machaeranthera scabrella (Greene) Shinners	NP	
Melampodium leucanthus T. & G. var. *leucanthus*	NP	Plains Blackfoot
Parthenium argentatum Gray	NP	Guayule, Rubber-Plant
Parthenium confertum Gray	NP	Lyreleaf Parthenium
Parthenium incanum H.B.K.	NP	Mariola
Pectis papposa Gray	NA	Many bristle Pectis
Perezia wrightii Gray	NP	Brownfoot
Perityle parryi Gray	NP	Heartleaf Perityle
Porophyllum scoparium Gray	NP	Poreleaf
Psilostrophe tagetina (Nutt.) Greene	NP	Wooly Paperflower
Senecio douglasii DC. var. *jamesii* (T. & G.) Ediger	NP	Threadleaf Groundsel
Senecio imparipinnatus Klatt.	NA	Groundsel
Sonchus asper (L.) Hill	IA	Prickly Sowthistle

Stephanomeria pauciflora (Torr.) A. Nels.	NP	Desert Skeletonplant
Trixis californica Kell.	NP	Amercan Trixis
Verbesina encelioides (Cav.) Gray	NA	Cowpen Daisy
Viguiera dentata (Cav.) Spreng.	NP	Sunflower Goldeneye
Viguiera stenoloba Blake	NP	Resin Bush
Xanthocephalum microcephalum (DC.) Shinners	NP	
Xanthocephalum sphaerocephalum (Gray) Shinners	NA	Threadlead Snakeweed
Zexmenia brevifolia Gray	NP	Shorthorn Z.
Zinna acerosa (DC.) Gray	NP	Spinyleaf Zinna

VERTEBRATE FAUNA OF THE BOFECILLOS MOUNTAINS, PRESIDIO COUNTY, TEXAS

Rick L. LoBello

A baseline survey of the vertebrate fauna was made in the Bofecillos Mountains region of Presidio County, Texas, November 7-11, 1975. In addition to these five days, a brief birding trip was made to the Ojitto Adentro area on December 24.

The Bofecillos region lies within the Chihuahuan biotic province as described by Dice (1943) and Blair (1950) and is situated in the southwestern portion of Presidio County. The area surveyed falls within Blair and Miller's (1949) description of the Roughland Life Belt. The vegetation is typically Chihuahuan desert shrub with spring areas, such as Ojitto Adentro and Rancherias Spring, supporting both cottonwoods and willows.

Our base camp was on the Big Bend Ranch of the Diamond-A Cattle Company and was situated a short distance southeast of Agua Adentro Mountain. From here we surveyed the area between camp and the northwestern part of Tapado Canyon, Tapado Canyon south to Oso Spring, and the areas around Rancherias Spring and Ojitto Adentro.

The vertebrate fauna of this region has not been previously studied. Baseline surveys were conducted during the summer, fall, and winter of 1975 in selected areas to the immediate east and south by Scudday (1976b, 1976c) in Fresno and Colorado Canyons and by Scudday (1976a) and LoBello (1976) in the Solitario. More intensive survey work has been conducted in the La Mota Mountain region to the immediate north (Milstead 1953 and Tamsitt 1954); in the Sierra Vieja to the northwest (Blair and Miller 1949, Jameson and Flury 1949, and Phillips, Homer, and Thorton 1949), and in Big Bend National Park to the east (Borell and Bryant 1942, Degehnardt 1969, and Wauer 1973).

Fresno Canyon, Colorado Canyon, and the Solitario are vegetatively similiar to the Bofecillos Mountains. Faunal compositions are also assumed to be similiar. Dissimilarities do occur between the faunas of the Bofecillos and those of the Sierra Vieja and Big Bend National Park areas. All the faunas, however, fall well within the range of those expected to occur within the boundaries of the Chihuahuan Desert.

Our base camp in the Bofecillos was approximately 138 km (86 mi) southeast of the Sierra Vieja study area and 55 km (34 airline mi) from the western boundary of Big Bend National Park. Because of the biotic similarities of these areas, comparisons of vertebrate lists for the Sierra Vieja and Big Bend National Park may indicate a variety of vertebrates not already recorded for the Bofecillos. Any vertebrates common to Roughland Life Belt lists of both can be assumed to be suspected species for the Bofecillos area.

I am indebted to Stephen Wagner and George Pool for their field assistance and to other members of the Texas Natural Areas Survey field teams for supplying me with helpful vertebrate locality information. In particular, I would like to thank Gary Moore and Dwight Deal. For critically reading the manuscript and many helpful suggestions, I wish to thank Dr. James F. Scudday.

HERPETOFAUNA OF THE BOFECILLOS

The latter part of November is certainly not the most productive time of year for collecting desert herps but, at times, can result in a fair sampling of an area. During a period of five days, 8 out of 43 suspected herps (two amphibians and six reptiles) were documented. A ninth documented species, *Salvadora grahamiae,* was brought to my attention by Dwight Deal when he visited Rancherias Springs in September, 1975. Additional collecting trips into the Bofecillos during more productive times of the year will undoubtedly document the occurrence of a much larger number of the suspected species.

In the herpetofauna list that follows, 43 species are listed for the Bofecillos Mountains region. The vast majority of these (marked with an asterisk) are represented on the basis of known range correlated with habitat preferences as referred in the literature (Jameson and Flury 1949; Milstead 1953; Conant 1975; LoBello 1976; Scudday 1976a, 1976b, 1976c).

REPTILES AND AMPHIBIANS OF THE BOFECILLOS MOUNTAINS

CLASS AMPHIBIA

Order Anura—Frogs and Toads

Family Leptodactylidae	**Syrrhophus guttilatus*—Mexican Cliff Frog
Family Bufonidae	**Bufo punctatus*—Red-spotted Toad
Family Hylidae	*Hyla arenicolor*—Canyon Treefrog
Family Microhylidae	**Gastrophryne olivacea*—Great Plains Narrow-mounthed Toad
Family Ranidae	*Rana berlanderi*—Rio Grande Leopard Frog

CLASS REPTILIA

Order Squamata—Snakes and Lizards

Suborder Lacertilia—Lizards

Family Gekkonidae	**Coleonyx brevis*—Texas Banded Gecko
	**Coleonyx reticulatus*—Reticulated Gecko
Family Iquanidae	**Crotaphytus collaris*—Collared Lizard
	Cophosaurus texanus—Texas Earless Lizard
	Phrynosoma modestum—Round-tailed Horned Lizard
	**Sceloporus magister*—Desert Spiny Lizard
	**S. merriami*—Canyon Lizard
	S. poinsetti—Crevice Spiny Lizard
	**S. undulatus*—Eastern Fence Lizard
	**Uta stansburiana*—Slide-blotched Lizard
Family Scincidae	**Eumeces brevilineatus*—Short-lined Skink
	**E. obsoletus*—Great Plains Skink
Family Teiidae	*Cnemidophorus inornatus*—Little Striped Whiptail
	**C. septemvittatus*—Rusty-rumped Whiptail
	**C. tesselatus*—Checkered Whiptail
	**C. tigris*—Western Whiptail

Suborder Serpentes—Snakes

Family Leptotyphlopidae	**Leptotyphlops humilis*—Western Blind Snake
Family Colubridae	**Diadophis punctatus*—Ring-necked Snake
	**Elaphe subocularis*—Trans-Pecos Ratsnake
	**E. guttata emoryi*—Emory's Rat Snake
	**Gyalopion conum*—Hook-nosed Snake
	**Hypsiglena torquota*—Night Snake
	**Lampropeltis mexicana*—Gray-banded Kingsnake
	**Masticophis flagellum*—Coachwhip
	**M. taeniatus*—Striped Whipsnake
	**Arizona elegans*—Glossy Snake
	Pituophis melanoleucus—Bullsnake
	**Rhinocheilus lecontei*—Long-nosed Snake
	**Sonora semiannulata*—Western Ground Snake
	Salvadora grahamiae—Mountain Patch-nosed Snake
	**Tantilla atriceps*—Mexican Black-headed Snake
	**Thamnophis cyrtopis*—Black-necked Garter Snake
	T. marcianus—Checkered Garter Snake
	**Trimorphodon biscutatus*—Lyre Snake
Family Viperidae	**Agkistrodon contortrix pictogaster*—Trans-Pecos Copperhead
	**Crotalus atrox*—Western Diamondback Rattlesnake
	**C. lepidus*—Mottled Rock Rattlesnake
	**C. molossus*—Black-tailed Rattlesnake
	**C. scutulatus*—Mojave Rattlesnake

TABLE 2

SUMMARY OF BOFECILLOS BIRD OBSERVATIONS

Species	Locality: Base Camp	Tapado Canyon	Rancherias Spring	Ojitto (November)	Ojitto (December)
Cooper's Hawk			X		
Red-tailed Hawk	X	X		X	
Golden Eagle		X			X
Scaled Quail	X			X	X
Killdeer			X		
Common Snipe			X		
White-winged Dove			X		
Mourning Dove	X			X	X
Roadrunner			X	X	
Screech Owl				X	
Great Horned Owl				X	
Poor-will	X				
Golden-fronted Woodpecker		X			
Yellow-bellied Sapsucker				X	
Black Phoebe	X		X	X	
Say's Phoebe	X		X		
Common Raven	X		X	X	
Verdin				X	
Cactus Wren	X	X	X		
Rock Wren			X	X	
Canyon Wren	X			X	
Mockingbird	X		X	X	X
Hermit Thrush			X	X	X
Black-tailed Gnatcatcher	X			X	
Ruby-crowned Kinglet		X	X	X	X
Water Pipit			X		
Loggerhead Shrike	X				
Meadowlark	X				
Cardinal			X	X	
Pyrrhuloxia	X	X	X	X	
House Finch	X		X		
Lesser Goldfinch	X			X	
Green-tailed Towhee			X	X	
Brown Towhee	X		X	X	X
Lark Bunting	X				
Black-throated Sparrow	X			X	X
Oregon Junco		X	X	X	X
Gray-headed Junco	X		X		
Rufous-crowned Sparrow	X				
Chipping Sparrow	X		X	X	X
Clay-colored Sparrow	X				
White-crowned Sparrow					X

Annotated List of Species

Rana berlandieri. – These frogs were commonly encountered at two localities: Rancherias Springs and Ojitto Adentro.

Hyla arenicolor. – This hearty little frog was collected from Tapado Canyon, Rancherias Springs, and Ojitto Adentro. In Tapado Canyon it was always found wherever small pools of water were present.

Cophosaurus texanus. – One specimen was collected along a wash just above the northwesternmost arm of Tapado Canyon.

Phrynosoma modestum. – One specimen was collected from within Tapado Canyon where it was found dead and partially decayed in the bottom of a shallow tinaja. This tinaja was located in a very narrow side canyon just below a 30-m dry water fall in Tapado Canyon. I suspect that this specimen was washed into this area from its more preferred habitat in the higher desert.

Sceloporus poinsetti. – This lizard was the most commonly encountered reptile throughout the study area. It was collected from within Tapado Canyon and at Ojitto Adentro. It was most often found associated with large boulders.

Cnemidophorus inornatus. – This whiptail was collected from only one locality, 1 km south of base camp near a hunter's camp.

Pituophis melanoleucus. – A large individual was encountered in the morning alongside the upper east-facing slope of Tapado Canyon, near the northernmost end. Estimated to be about 1.7 m long, the snake was captured, photograph, and released.

Salvadora grahamiae. – Dwight Deal collected a specimen from near the waterfalls at Rancherias Springs on September 27, 1975. The specimen was later preserved and deposited in the Sul Ross State University Collection.

Thamnophis marcianus. – Four individuals of this species were observed at Rancherias Springs. Two captives escaped before they could be preserved.

AVIFAUNA OF THE BOFECILLOS

From June 5 to July 9, 1958, Phillips and Thorton (1949) recorded 41 species of birds from within the Roughland Life Belt of the Sierra Vieja. Their list and the Bofecillos list of 42 species, summarized in Table 1 for the week of November 7-11 and December 24, 1975, are considered incomplete.

Using recent data from the Solitario (LoBello 1976; Scudday 1976a) and Fresno Canyon (Scudday 1976b), a list of recorded and suspected birds of the Bofecillos Mountains has been assembled.

In the list that follows, 107 species (33 families) are represented for the Roughland Life Belt. As additional work is carried out, more species will undoubtedly be verified for the area. For example, birds known from both the Sierra Vieja and Big Bend National Park may also be found in the Bofecillos. This would include such species as the Band-tailed Pigeon, Violet-Green Swallow, and Lazuli Bunting.

LIST OF RECORDED AND SUSPECTED BIRDS OF THE BOFECILLOS MOUNTAINS REGION

Asterisk (*) denotes suspected species as referenced from work in the Solitario (Lobello 1976; Scudday 1976a)
Plus (+) denotes reference to work in Fresno Canyon (Scudday 1976b)

Order Anseriformes		
	Family Anatidae	+*Anas diazi*—Mexican Duck
		**A. carolinensis*—Green winged Teal
		+*A. cyanoptera*—Cinnamon Teal
		**Spatula clypeata*—Shoveler
Order Falconiformes		
	Family Cathartidae	**Cathartes aura*—Turkey Vulture
	Family Accipitridae	+*Accipiter striatus*—Sharp-shinned Hawk
		A. cooperii—Cooper's Hawk
		Buteo jamaicensis—Red-tailed Hawk
		**B. swainsoni*—Swainson's Hawk
		+*B. albonotatus*—Zone-tailed Hawk
		**B. regalis*—Ferruginous Hawk
		Aquila chrysaetos—Golden Eagle
		**Circus cyaneus*—Marsh Hawk
		**Falco sparverius*—Sparrow Hawk

Order Galliformes
Family Phasianidae . . . . *Callipepla squamata*—Scaled Quail
Order Charadriiformes
Family Charadriidae . . . . *Charadrius vociferus*—Killdeer
Family Scolopacidae . . . . +*Actitis macularia*—Spotted Sandpiper
Capella gallinago—Common Snipe
Order Columbiformes
Family Columbidae . . . . *Zenaida asiatica*—White-winged Dove
Z. macroura—Mourning Dove
+*Columbigallina passerina*—Ground Dove
Order Cuculiformes
Family Cuculidae . . . . +*Coccyzus americanus*—Yellow-billed Cuckoo
Geococcyx californicus—Roadrunner
Order Strigiformes
Family Tytonidae . . . . +*Tyto alba*—Barn Owl
Family Strigidae . . . . *Otus asia*—Screech Owl
Bubo virginianus—Great-Horned Owl
**Micrathene whitneyi*—Elf Owl
Order Caprimulgiformes
Family Caprimulgidae . . . . *Phalaenoptilus nuttallii*—Poor-will
**Chordeiles acutipennis*—Lesser Nighthawk
**C. minor*—Common Nighthawk
Order Apodiformes
Family Apodiformes . . . . **Aeronautes saxatalis*—White-throated Swift
Family Trochilidae . . . . +*Selasphorus platycercus*—Broad-tailed Hummingbird
+*S. rufus*—Rufous Hummingbird
**Archilochus alexandri*—Black-chinned Hummingbird
+*Calothorax lucifer*—Lucifer's Hummingbird
Order Piciformes
Family Picidae . . . . **Coloptes cafer*—Red-shafted Flicker
Centurus aurifrons—Golden-fronted Woodpecker
**Dendrocopos scalaris*—Ladder-backed Woodpecker
Sphyrapicus varius—Yellow-bellied sapsucker
Order Passeriformes
Family Tyrannidae . . . . +*Pyrocephalus rubinus*—Vermilion Flycatcher
+*Tyrannus verticalis*—Western Kingbird
**Myiarchus cinerascens*—Ash-throated Flycatcher
**Sayornis phoebe*—Eastern Phoebe
S. nigricans—Black Phoebe
S. saya—Say's Phoebe
+*Empidonax sp.*
**Contopus Sordidulus*—Western Wood Pewee
Family Hirundinidae . . . . +*Hirundo rustica*—Barn Swallow
**Petrochelidon pyrrhonota*—Cliff Swallow
+*Stelgidopteryx ruficollis*—Rough-winged Swallow
Family Corvidae . . . . **Aphelocoma coerulescens*—Scrub Jay
**Corvus eryptoleucus*—White-necked Raven
C. corax—Common Raven
Family Paridae . . . . +*Parus atricristatus*—Black-crested Titmouse
Auriparus flaviceps—Verdin
Family Troglodytidae . . . . +*Troglodytes aedon*—House Wren
+*T. bewickii*—Bewick's Wren
Campylorhynchus brunneicapillus—Cactus Wren
Salpinctes obsoletus—Rock Wren
Catherpes mexicanus—Canyon Wren

Family Mimidae .... *Mimus polyglottos*—Mockingbird
**Toxostoma curvirostre*—Curve-billed Thrasher
**T. dorsale*—Crissal Thrasher
Family Turdidae .... *+Turdus migratorius*—Robin
Hylocichla guttata—Hermit Thrush
Family Sylviidae .... *+Polioptila caerulea*—Blue-gray Gnatcatcher
P. melanura—Black-tailed Gnatcatcher
Regulus calendula—Ruby-crowned Kinglet
Family Bombycillidae .... *+Bombycilla cedrorum*—Cedar Waxwing
Family Lannidae .... *Lanius ludovicianus*—Loggerhead Shrike
Family Ptilogonatidae .... *+Phainopepla nitens* —Phainopepla
Family Vireonidae .... *+Vireo vicinior*—Gray Vireo
+ V. solitarius—Solitary Vireo
**V. bellii*—Bell's Vireo
Family Parulidae .... *+Vermivora celata*—Orange-crowned Warbler
**Dendroica coronata*—Myrtle Warbler
**D. auduboni*—Audubon's Warbler
**D. townsendi*—Townsend's Warbler
+Icteria virens—Yellow-breasted Chat
**Oporonis tolmiei*—MacGillivray's Warbler
**Wilsonia pusilla*—Wilson's Warbler
Family Ploceidae .... *+Passer domesticus*—House Sparrow
Family Icteridae .... *Sturnella sp.*—Meadowlark
**Euphagus cyanocephalus*—Brewer's Blackbird
+Icterus spurius—Orchard Oriole
**I. parisorum*—Scott's Oriole
+I. bullockii—Bullock's Oriole
+Molothrus ater—Brown-headed Cowbird
Family Thraupidae .... **Piranga ludoviciana*—Western Tanager
**P. rubra*—Summer Tanager
Family Fringillidae .... *Richmondena cardinalis*—Cardinal
Pyrrhuloxia sinuata—Pyrrhuloxia
+Guiraca caerulea—Blue Grosbeak
+Passerina versicolor—Varied Bunting
+P. ciris—Painted Bunting
Carpodacus mexicanus—House Finch
**Spinus pinus*—Pine Siskin
S. psaltria—Lesser Goldfinsh
Chlorura chlorura—Green-tailed Towhee
**Pipilo erythrophthalmus*—Rufus-sided Towhee
P. fuscus—Brown Towhee
Calamospiza melanocorys—Lark Bunting
+Pooecetes gramineus—Vesper Sparrow
+Chondestes gramineus—Lark Sparrow
Amphispiza hilineata—Black-throated Sparrow
Junco hyemalis oreganus—Oregon Junco
J. caniceps—Gray-headed Junco
Aimophila ruficeps—Rufous-crowned Sparrow
**A. cassinii*—Cassin's Sparrow
Spizella passerina—Chipping Sparrow
S. pallida—Clay-colored Sparrow
Zonotrichia leucophrys—White-crowned Sparrow
+Melospiza lincolnii—Lincoln's sparrow

Several of the birds recorded for the Bofecillos region are worthy of special note. The golden eagle probably is a nesting bird in the area. On November 8, 1975, a pair of eagles consisting of an immature and an adult was seen twice in Tapado Canyon, once flying over the northwesternmost arm and once above Oso Springs. On December 24, another adult was seen hovering over the entrance to Ojitto Adentro Canyon. I observed it entering a large stick nest on the south-facing slope of that small closed canyon.

The common snipe sighting at Rancherias Springs is significant because it has rarely been recorded in West Texas away from the Rio Grande floodplain. Wauer (1973) lists it as occurring only at Rio Grande Village and Cottonwood Campground in Big Bend National Park. Van Tyne and Sutton (1937) recorded migrant birds at Garden Springs, Ridge Springs, Calamity Creek 35.5 k (22 mi), S. Alpine, and at a tank 27.3 km (17 mi) northeast of Marathon.

Another worthy mention concerns the distribution of white-winged doves in the Bofecillos area. Wauer (1973) has noted that white-wings in Big Bend National Park are found mainly "along the river, in adjacent washes, at springs below 1500 m (5000 ft) elevation, and locally within the lower canyons of the Chisos Mountains." The question arises why white-wings were recorded only at Rancherias Springs in the Bofecillos and nowhere else. The localities in the Bofecillos where they were suspected, but not found, included Oso Springs in Tapado Canyon and Ojitto Adentro. Hunting pressure is an unlikely explanation for this distribution, but no documentation exists to support this hypothesis.

The sighting of a golden-fronted woodpecker at Oso Springs on November 8 is significant, since it represents a new species record for Presidio County. This bird is known to breed in Brewster County along Calamity Creek, south of Alpine (Wauer 1973).

Gary Moore also reported sighting turkey tracks in the head of Las Burras Canyon. A turkey was sighted in mesquite brush in Fresno Canyon by Winckler (Scudday 1976a). Turkeys here are presumed to be introduced stock.

MAMMALS OF THE BOFECILLOS

In the list that follows, fourteen species of mammals were recorded for the Bofecillos region. On the basis of previous work in the surrounding area (Blair and Miller 1949; Tamsitt 1954; LoBello 1976; Scudday 1976a, 1976b, 1976c), the wide-ranging species that went unrecorded have been added as suspected for the region (marked with an asterisk). Scudday (1976b) also lists an additional ten species of bats, six rodents, and one exotic Bovid for the Fresno Canyon area. Any one of these mammals may turn up in the Bofecillos, but it seems safer to leave them off the list until further work can be completed.

Most of the mammal data for the area came from trapping operations, using Sherman live-traps and Victor collapsible large mammal live-traps. Live-trapping for large mammals in Tapado Canyon, the washes around our base camp, and at Ojitto Adentro was unsuccessful after an estimated 40 trap-nights.

Steel-trapping operations carried out by the Big Bend Ranch in an effort to eradicate mountain lions revealed additional data for Tapado Canyon. Within the canyon itself, we came across a steel-trapped javelina and a gray fox. The ranch foreman, Ralph Hager, showed us a large male mountain lion carcass that his trapper had recently caught in one of the canyons. Although sheep are not present on the ranch, the mountain lion does take an occasional colt, causing an economic loss to the ranch. The trapper, referred to as "Candy," claimed to have trapped 11 mountain lions on the ranch during the year 1975. Scudday (1976a) also cites mountain lion trapping operations in and around the Solitario region.

Bat-netting operations in the Bofecillos region were unsuccessful because of the high winds that came up almost every night that we were there. One area that seemed to be an especially good prospect for bats was the Rancherias Springs area. Here a large amount of water flows into pools of various sizes. This area should definitely be bat-netted again in the future.

Table 2 summarizes known localities for mammals recorded in the Bofecillos region. Localities not mentioned are as follows: Gary Moore informed me of finding mountain lion signs and antelope ground squirrels in Las Burras Canyon, while I have two skunk records for the Presidio highway situated about 40 km (24 mi) west of our base camp. On November 11, 1975, I observed a hog-nosed skunk crossing the highway just north of Presidio. While dove-hunting out on a creosote flat about 8 km (5 mi) north of Presidio in October, 1974, I also encountered a spotted skunk foraging around dusk. Skunk records for West Texas are scattered, and much more still needs to be learned about their distribution.

CONCLUSION

The composition of the vertebrate fauna of the Bofecillos Mountains region will become better known with each visit. When compared to other Roughland Life Belt areas analyzed by Texas Natural Area Surveys, such as Fresno Canyon and the Solitario, the diversity of vertebrates found in the Bofecillos is probably more similar to that of Fresno

MAMMALS OF THE BOFECILLOS

Order Chiroptera
- Family Vespertilionidae .... *Pipistrellus hesperus*—Canyon Bat

Order Lagomorpha
- Family Leporidae .... *Lepus californicus*—Jack Rabbit
  - *Sylvilagus audubon*i—Desert Cottontail

Order Rodentia
- Family Sciuridae .... *Spermophilus variegatus*—Rock Squirrel
  - *Ammospermophilus interpres*—Texas Antelope Ground Squirrel
- Family Heteromyidae .... *Perognathus penicillatus*—Desert Pocket Mouse
  - *P. merriami*—Merriam's Pocket Mouse
  - *Dipodomys merriami*—Merriam's Kangaroo Rat
- Family Cricetidae .... *Peromyscus pectoralis*—Encinal Mouse
  - **Neotoma albigula*—White-throated Woodrat
- Family Erethizontidae .... **Erethizon dorsatum*—Porcupine

Order Carnivora
- Family Canidae .... **Canis latrans*—Coyote
  - *Urocyon cinereoargenteus*—Gray Fox
  - **Vulpes macrotis*—Kit Fox
- Family Ursidae .... **Ursus americanus*—Black Bear
- Family Procyonidae .... **Procyon lotor*—Raccoon
  - *Bassariscus astutus*—Ringtail Cat
- Family Felidae .... *Felis concolor*—Mountain Lion
  - **Lynx rufus*—Bobcat
- Family Mustelidae .... **Mephitis mephitis*—Striped Skunk
  - **Spilogale gracilis*—Spotted Skunk
  - **Conepatus mesoleucus*—Hog-nosed Skunk
  - **Taxidea taxus*—Badger

Order Artiodactyla
- Family Tayassuidae .... *Tayassu tajacu*—Javelina
- Family Cervidae .... *Odocoileus hemionus*—Mule Deer

TABLE 2

MAMMALS RECORDED IN THE BOFECILLOS REGION, PRESIDIO COUNTY, TEXAS

Species	Locality: Base Camp	Tapado Canyon	Rancherias Springs	Ojitto Adentro	Bofecillos Canyon*
Canyon Bat	X				
Jack Rabbit	X		X		X
Desert Cottontail		X	X	X	X
Rock Squirrel		X	X	X	
Texas Antelope Ground Squirrel					X
Desert Pocket Mouse	X		X	X	
Merriam's Pocket Mouse	X		X		
Merriam's Kangaroo Rat	X		X		
Encinal Mouse	X		X	X	
Gray Fox		X			
Ringtail Cat		X			
Mountain Lion		X			
Javelina		X			
Mule Deer				X	

Canyon than the Solitario. This hypothesis can be best supported by studying the availability of water in these three areas. Since a number of Passeriforms and chiropters require localized watering areas, a greater diversity in the two vertebrate classes can be expected in areas with more available water. The Solitario area simply has very few pools of available water, and the availability of water in the Bofecillos (Oso Spring, Ojitto Adentro, and Rancherias Spring) and in Fresno Canyon is much greater.

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BUTTERFLIES OF THE SOLITARIO – FRESNO CREEK – BOFECILLOS MOUNTAINS REGION WESTERN BIG BEND (PRESIDIO AND BREWSTER COUNTIES) TEXAS

Christopher J. Durden

Forty-seven species of butterflies in the western Big Bend region were recorded during collecting visits in May 1973, October 1974, and June 1975. Although this list is perhaps less than one-half of the potential, it is possible to draw some conclusions regarding the faunal affinities of the area.

There are a few taxa of restricted range. Two are restricted to the immediate Big Bend Region of West Texas (including the Davis Mountains): *Megisto rubricata smithorum* and *Thessalia chinatiensis.* Two are restricted to a narrow band, and extension of the Sierra Madre Oriental of Mexico: *Strymon* new species and *Celotes limpia.* One occurs throughout the Rio Grande basin below Albuquerque and westward through the Lordsburg gap over surfaces drained by the ancestral Rio Mimbres (R. C. Belcher 1975:44) in mid-Tertiary time: *Dymasia dymas.* One is a western disjunct of a Tamaulipan shrubland species: *Thessalia theona bollii.* Four are Sonoran desert species either disjunct or at the eastern edge of their ranges (which pass through the Lordsburg gap): *Chlosyne lacinia crocale, Asterocampa leila, Asterocampa subpallida,* and *Systasea zampa.*

Four species are widely distributed in both Sonoran and Chihuahuan deserts: *Papilio rudkini clarki, Calephelis nemesis, Cogia hippalus,* and *Atrytonopsis ovinia edwardsi.* Two have a Kansan Province (short grass prairie) distribution and are at the southern end of their range: *Phyciodes picta* and *Amblyscirtes oslari.* One eastern deciduous forest species is disjunct here and in Durango: *Polygonia interrogationis.* One is eastern Neotropical, extending into the eastern Great Plains: *Agraulis vanillae incarnata.*

Ten species have broad ranges on either side of the continental divide but do not extend south of Northern Mexico: *Papilio polyxenes curvifascia, Eurema mexicana, Thessalia fulvia, Limenitis bredowii eulalia, Phyciodes vesta, Leptotes marina, Strymon melinus franki, Atlides halesus corcorani, Icaricia acmon texanus, Hesperia pahaska williamsi.* Five species have broad ranges on both sides of the continental divide, mostly in Mexico: *Phoebis sennae marcellina, Kricogonia lyside, Danaus gilippus strigosus, Libytheana carinenta mexicana,* and *Copaeodes aurantiaca.*

Six species have very broad temperate ranges: *Pieris protodice, Colias eurytheme, Danaus plexippus, Euptoieta claudia, Hemiargus isola alce,* and *Pyrgus communis.* Six species have very broad subtropical ranges: *Battus philenor, Nathalis iole, Eurema nicippe, Zerene cesonia, Brephidium exilis,* and *Erynnis funeralis.* Two species range throughout North America: *Vanessa virginiensis* and *Vanessa cardui.*

The chief surprises are the lack of uniquely Chihuahuan Desert species. Species endemic to the Big Bend will probably be found south of the Rio Grande in the isolated ranges of western Coahuila and eastern Chihuahua. Endemic species of the northern Sierra Madre Oriental occur in arid habitats and should be assigned to the Chihuahuan Desert fauna (they are not likely however to be found in Chihuahua). Disjuncts from both Tamaulipan and Sonoran provinces suggest that the Rio Grande has been an important route of dispersal. The several species that leak through the Lordsburg Gap from the Sonoran desert indicate that this mid-Tertiary segment of the Rio Grande drainage, the ancestral Mimbres-upper Gila River of mid-Miocene to mid-Pliocene time (Belcher 1975:38), has been and continues to be an important passage for extension of ranges of both eastern and western desert species.

Locality Register

All voucher specimens are numbered as follows: First two digits are last two of the year, next three digits are day of the year, followed by a punctuating letter designating site collected during the day, terminated by unique specimen number. Number is prefixed by collector's name in citation.

Solitario Localities

Brewster County

Lefthand Shutup (103.75-6°W, 29.47°N): 73141J, 75162B.

Tres Papalotes (103.77°W, 29.45°N): 73141H, 75159A (part).

Summit and ridge south of Tres Papalotes (103.77°W, 29.44°N): 75159A (part).

SUMMARY OF OCCURRENCE OF BUTTERFLIES IN THE SOLITARIO (S), FRESNO CREEK (F), AND BOFECILLOS MOUNTAINS (B) OF WESTERN BIG BEND, TEXAS

1	*Battus philenor*	S	F	
2	*Papilio polyxenes curvifascia*	S	F	
3	*Papilio rudkini clarki*	S	F	
4	*Pieris protodice*	S		
5	*Nathalis iole*		F	
6	*Colias eurytheme*	S		
7	*Zerene cesonia*		F	
8	*Eurema mexicana*	S		
9	*Eurema nicippe*	S	F	B
10	*Phoebis sennae marcellina*		F	
11	*Kricogonia lyside*		F	
12	*Danaus gilippus strigosa*	S	F	B
13	*Danaus plexippus*			F
14	*Megisto rubricata smithorum*	S	F	
15	*Agraulis vanillae incarnata*		F	
16	*Euptoieta claudia*		F	
17	*Polygonia interrogationis*		F	
18	*Vanessa virginiensis*	S		
19	*Vanessa cardui*	S		
20	*Chlosyne lacinia crocale*	S		
21	*Thessalia chinatiensis*	S		
22	*Thessalia theona bollii*	S		
23	*Thessalia fulvia*	S		
24	*Dymasia dymas*		F	
25	*Phyciodes vesta*	S	F	
26	*Phyciodes picta*		F	
27	*Limenitis bredowii eulalia*		F	
28	*Asterocampa leila*	S	F	B
29	*Asterocampa subpallida*			B
30	*Libytheana carinenta mexicana*		F	
31	*Calephelis nemesis*		F	B
32	*Atlides halesus corcorani*		F	
33	*Strymon melinus franki*	S	F	
34	*Strymon* new species	S	F	
35	*Brephidium exilis*	S		
36	*Hemiargus isola alce*	S	F	B
37	*Leptotes marina*	S	F	B
38	*Icaricia acmon texanus*	S		B
39	*Cogia hippalus*			B
40	*Systasea zampa*			B
41	*Erynnis funeralis*	S	F	
42	*Celotes limpia*	S		B
43	*Pyrgus communis*	S		B
44	*Copaeodes aurantiaca*	S	F	
45	*Herperia pahaska williamsi*		F	
46	*Amblyscirtes oslari*	S		
47	*Atrytonopsis ovinia edwardsi*	S	F	

Presidio County

Fresno Peak (103.83°W, 29.42°N): 75162A (part).

Chert ridge and gulch south of Middle Tank (103.81°W, 29.44°N): 75162A (part).

Middle Tank (103.81°W, 29.44°N): 75161C (part).

Grays Ridge Gulch (103.81°W, 29.44°N): 75161C (part), 73140E.

Grays Ridge (103.80°W, 29.43°N): 73140D.

Lower Shutup (103.80°W, 29.41°N): 73140A.

Righthand Shutup to Solitario Peak (103.84-5°W, 29.45-6°N):73136C.

Rim of Solitario and limestone summit west of Solitario Peak (103.84°W, 29.46°N): 73136A.

Southwest chimney of Solitario Peak (103.84°W, 29.46°N): 73136B.

Gulch and limestone summit north of Solitario Peak (103.84°W, 29.46°N): 75160A.

East slope of Solitario Peak (103.83°W, 29.46°N): 73140C, 75160A (part).

South slope of Solitario Peak (103.83°W, 29.46°N): 75161A.

Localities in the Western Drainage of Fresno Creek

Presidio County

Log Spring Draw (103.87°W, 29.45°N): 73137B.

Slopes above Log Spring Draw (103.87°W, 29.45°N): 73137A.

Seep Springs Draw (103.86°W, 29.44°N): 73137C.

Upper and Lower Seep Springs (103.87°W, 29.44°N): 73138A.

Summit and slopes west of Seep Springs (103.88°W, 29.45°N): 73137B.

Smith Ranch (103.86°W, 29.39°N): 73135A (part).

Smith Spring Draw (103.87°W, 29.39°N): 73135A (part).

Rancho Madrid (103.87°W, 29.37°N): 73138D, 74293B.

Chorro Canyon below Madrid Falls (103.88°W, 29.37°N): 73138C, 74291A, 74293A.

Chorro Canyon above Madrid Falls (103.88°W, 29.38°N): 73138F, 74292B.

Localities in the Bofecillos Mountains

Presidio County

Bofecillos Canyon, springs below pictographs (104.10°W, 29.49°N): 73142A.

Lower Tapado Canyon, springs above main fork (104.08°W, 29.38°N): 73143A.

All voucher specimens are curated in the Ecological and Systematic Survey of Texas Arthropods (ESSTA) Collection of Texas Memorial Museum, 2400 Trinity Street, Austin, Texas 78705, and are available for study by qualified investigators.

Family PAPILIONIDAE

Battus philenor Linnaeus, 1771. 73138D1 Rancho Madrid, 75162A1 Fresno Peak.

This black and blue, glossy, orange-spotted swallowtail is conspicuous throughout the area and may be seen on warm days almost all year. It was present in hilltopping assemblages at Seep Springs summit and on Fresno Peak, and was seen flying along washes west of Fresno Creek and in the Shutups of the Solitario. Adults frequently feed at the blooms of desert willow *Chilopsis linearis,* and the larvae feed exclusively on species of *Aristolochia.*

Papilio polyxenes curvifascia Skinner, 1902. 73137B sight Seep Springs summit, 75159A5-9 Tres Papalotes summit, 75160A9 summit N of Solitario Peak.

This yellow-spotted, black swallowtail was a frequent component of hilltopping assemblages on the summit north of Chorro Canyon, summit west of Seep Springs, rim summits west of Solitario Peak, Solitario Peak, and Gray's Ridge. It is distinguished from its sibling *P. rudkini* by the odor (resembling cheap perfume) of the androconial scales of the male forewing, the irregularly aligned and rough-edged spots of the post-median yellow band, the coarse or fluffy appearance of the wing scales, and the black cast of the ventral proximal dark area of the wings. Where *P. polyxenes* occurs in arid regions, in potential sympatry with *P. rudkini,* it is represented by the subspecies *curvifascia* and individuals resembling the eastern subspecies, *asterius* Stoll, are uncommon. Larvae of *P. polyxenes* feed on Umbelliferae and the occasional reports of Rutaceae may refer to individuals of the following species.

Papilio rudkini clarki Chermock & Chermock, 1937. 73140D2 Gray's Ridge, 73137B1 Seep Springs summit, 75162A2 Fresno Peak.

This very close sibling species is distinguished from *P. polyxenes* by the odor (citrus) of the androconia or scent scales of the male forewing, the straighter alignment of the more evenly bordered post-median spotband, the smoother appearance of the scales, and the gray cast of the ventral proximal dark area of the wings. *P. r. clarki* is the dark form of the species found in areas where *P. rudkini* and *P. polyxenes* are sympatric, from eastern California through eastern Arizona to southern Colorado, eastern New Mexico, and the Edwards Plateau (Travis County) of Texas. Its range southward in the Chihuahuan Desert region has not been documented. It is found in arid habitats; rock summits in the west; gravel-covered river terraces and talus in the east. *P. rudkini* larvae feed on Rutaceae, particularly species of *Thamnosma. P. r. clarki* appears to grade into the Central American *P. americus stabilis* Rothschild and Jordan in South Texas (Hays and Bexar Counties). When details of its biology are worked out *clarki* (and other races of *rudkini* and *coloro* Wright) will probably be recognized as subspecies of *P. americus* Kollar as was predicted by Edwards in 1877.

Family PIERIDAE

Pieris protodice Boisduval & Leconte, 1829. 73136A1-2 summit west of Solitario Peak, 75159A11 summit south of Tres Papalotes, 75161C21-23 Middle Tank.

This common white desert butterfly is a frequent component of hilltopping assemblages. It is also encountered flying along washes where its larval foodplants, various cruciferous weeds, occur. It was commonly seen visiting the sunflowers on the graded area of Middle Tank.

Nathalis iole Boisduval 1836. 73138D sight Rancho Madrid.

This widespread species of desert and plains occurs in weedy areas along washes as well as on heavily grazed pasture where the foodplants are found. These include species of *Dysodia, Helenium, Stellaria, Bidens, Thelosperma,* and *Palafoxia.*

Colias eurytheme Boisduval, 1852. 75161C24 Middle Tank.

This temperate meadow species also occurs abundantly in desert areas along gulches where herbaceous legumes, the larval foodplants, grow. Adults habitually fly along gravel stream beds and are less frequently observed crossing open country. They are preadapted to fly along road shoulders, an artificial habitat also occupied by the larval foodplants. Hence the species has extended its range eastward in historic times. The species breeds year round at this latitude and numbers are highest in spring and fall.

Zerene cesonia Stoll, 1790. 73138D sight Rancho Madrid.

This species is an occasional hilltopper and is seen frequently flying across desert scrub in the Solitario. Adults are avid flower visitors, feeding at desert willow *Chilopsis linearis* and wild china *Sapindus saponaria.* The larvae feed on various herbaceous legumes.

Eurema mexicana Boisduval, 1836. 75161C25-26 Middle Tank.

This species ranges from tropical forest habitats in Central America to montane woodland sites in the Rocky Mountains. In the latter area the larval foodplant is *Robinia neomexicana.* In this area it may use *Cassia lindheimeriana* or one of the *Acacia* species.

Eurema nicippe Cramer, 1780. 73138D3 Rancho Madrid, 73141H1 Tres Papalotes, 73143A1 lower Tapado Canyon, 74291A7 lower Chorro Canyon, 75161C20 Middle Tank.

At times this is one of the commonest butterflies of the area. A small orange butterfly, it is seen frequently along washes and the lower valley flats where the principal foodplant senna, *Cassia linhdeimeriana,* grows. Adults may be found in warm weather at any time of year.

Phoebis sennae marcellina Cramer, 1777. 73138D2 Rancho Madrid, 74292B3 upper Chorro Canyon, 74293B3-4 Rancho Madrid.

This large, yellow-sulfur butterfly (which has both orange and white forms of the female) is seen infrequently along dry washes in all areas. Old adults have a strong odor of rancid butter. The larvae feed on various species of senna, *Cassia* spp. in a tent formed from a folded leaf, tied with silk.

Kricogonia lyside var. *terissa* Lucas, 1852. 73138D4 Rancho Madrid.

This species of the Chihuahuan Desert and Tamaulipan shrubland feeds, as larva, on guyacan, *Porlieria angustifolia.* A female was observed to oviposit on this shrub at upper Seep Spring. The species occurs as several genetically determined varieties and phenotypic forms of quite different appearance, the ecological significance of which is not yet understood. Under epidemic conditions, all named forms and varieties have been taken together. Following certain climatic events this species migrates in flocks of millions of individuals, often in the company of the snout butterfly, *Libytheana bachmanii.* Adults of *K. lyside,* when not in migration, tend to be crepuscular, or most active at dusk, when they gather in bushes about seeps and springs. Occasionally they congregate at the flowers of wild china, *Sapindus saponaria.*

Family NYMPHALIDAE

Danaus gilippus strigosa Bates, 1864. 73138D sight Rancho Madrid, 73135A sight Smith Ranch, 73137B sight Log Spring Draw, 73136C sight Righthand Shutup, 73140A sight Lower Shutup, 73141J sight Lefthand Shutup, 73142A3 Bofecillos Canyon, 74293B2 Rancho Madrid, 75161C5 Middle Tank.

This small, dull brown to tan monarch is frequent along washes where the foodplants (*Asclepias* spp.) of the larvae grow.

Danaus plexippus Linnaeus, 1758. 73138D9 Rancho Madrid, 74291A1 upper Chorro Canyon, 74293B1 Rancho Madrid.

A larger number of monarchs were seen in the area than was expected. In both May and October, most were in sustained flight along dry washes, but some were engaged in roosting activity in trees around Smith Spring and Seep Spring. No monarchs were seen in June, and it is unlikely that they breed in the area.

Megisto rubricata smithorum Wind, 1946. 73140C1 east slope Solitario Peak, 73138C1 lower Chorro Canyon, 73137B2-3 slopes of Seep Springs summit, 73136C1 dry wash west of Solitario Peak, 73136B1-6 SW chimney of Solitario Peak, 73135A1-4 Smith Spring draw, 74292B4 upper Chorro Canyon, 75159A2 ridge south of Tres Papalotes, 75160A1,7 east slope Solitario Peak, 75161C1 Gray's Ridge Gulch, 75162A3 chert ridge south of Middle Tank.

The subspecies *smithorum* is found in oak and juniper woodland habitats in the Davis and Chisos Mountains. Subspecies *rubricata* is found in oak and juniper woodland habitats of the Guadalupe Mountains, Wichita Mountains (Oklahoma), and Edwards Plateau. Subspecies *cheneyorum* occurs in oak and juniper woodland of eastern Arizona and southern New Mexico. An underscribed subspecies occurs in live oak woodland at the eastern edge of the Edwards Plateau and in the Serranias del Burro (Coahuila). The Solitario populations differ from but are closest to *smithorum.* They are the only nonwoodland race yet known of *M. rubricata.* Adults may be flushed from the tall tufted grasses, the probable larval foodplant, that grow on the steep upper talus slopes below chert or volcanic cliffs. It is in such situations that other woodland relicts are found, including scattered oaks. *M. rubricata* is found far beyond these oaks, however. The distribution of this species is probably relict from a time when much of the Solitario and Fresno Canyon were clothed in oak woodland.

Agraulis vanillae incarnata Riley, 1926. 73138D sight Rancho Madrid.

The gulf fritillary is usually found along well-vegetated washes where its larval foodplants, the vine *Passiflora* spp. grow.

Euptoieta claudia Cramer, 1776. 73137B sight Seep Springs summit.

This fritillary of the Great Plains and Mexican Plateau is abundant where heavy grazing has disturbed the grassland to the point that weedy plants such as *Portulaca* spp., *Sedum* spp., *Meibomia* spp., and *Plantago* spp. can act as larval foodplant. Larvae have also been found to eat many other plants, including species of *Viola, Passiflora, Menispermum,* and *Podophyllum* in other areas.

Polygonia interrogationis Fabricius, 1798. 74292B2 upper Chorro Canyon.

This widespread species of eastern North America is (except for a population in Durango), unusual west or south of the prairies and Edwards Plateau. As food, the larvae prefer species of *Celtis,* but will also eat species of *Ulmus, Humulus, Urtica,* and *Tilia.*

Vanessa virginiensis Drury, 1773. 73140A sight Lower Shutup, 75161C14 Middle Tank.

This is a common species of shrublands, where the larval foodplants are species of *Senecio, Artemisia, Anaphalis, Antennaria, Gnaphalium, Myosotis, Antirrhinum* and *Malva.* Adults may be found on warm days in winter.

Vanessa cardui Linnaeus, 1758. 73140C sight east slope Solitario Peak. 73141J sight Lefthand Shutup.

This is a common species of arid shrublands, where it utilizes as larval food species of *Malva, Althea, Borago, Cirsium, Carduus, Centaurea, Arctium, Anaphalis, Artemisia,* and *Gnaphalium.* The species is found on all continents except Australia. It breeds year round in the Sonoran, Chihuahuan, Saharan, Arabian, and Gobi deserts and emigrates annually to higher latitudes, having been taken at the northernmost point of Greenland.

Chlosyne lacinia crocale Edwards, 1874. 75159A10 summit south of Tres Papalotes, 75161C19 (near *adjutrix*) Middle Tank, 75162A5 (*crocale*), 6 (near *adjutrix*) Fresno Peak.

This butterfly is found in disturbed sites in arid regions on both sides of the continental divide. It is at the eastern edge of its range here and shows evidence of intergradation with the Tamaulipan *C. l. adjutrix.* The latter ranges northwest to the Texas Panhandle (Blackwater Draw) and eastern New Mexico. Typical *C. l. crocale* was unexpected in the Solitario. The larval foodplants include a number of species of sunflowers of several genera.

Thessalia chinatiensis Tinkham, 1944. 75161A2-3 south slope Solitario Peak, 75162A7-9 Fresno Peak.

This West Texas endemic occurs in the Chinati Mountains, at Toyahvale, and near Terlingua. In Big Bend National Park it is found at lower elevations than the related *T. thekla* Edwards, which feeds as larva on *Castilleja lanata* and *Verbena* in the Sonoran desert. *T. thekla* has not yet been found in the Solitario area, where *T. chinatiensis* is found at moderate and high elevations, and is always associated with *Castilleja* spp. On Fresno Peak *T. chinatiensis* flies with *T. fulvia.*

Thessalia theona bollii Edwards, 1877. 75159A4 summit south of Tres Papalotes.

This species of the Tamaulipan shrubland is at the western and northern extremity of its range here. In South Texas its larvae are known to eat *Leucophyllum texanum.* It was found here with *T. fulvia* on a shrubby summit.

Thessalia fulvia Edwards, 1879. 73137B4-5 Seep Springs summit, 75159A3 summit south of Tres Papalotes, 75160A3-6 summit north of Solitario Peak, 75161C17-18 slopes above Gray's Ridge Gulch, 75162A10-13 Fresno Peak.

This species is found on dry, rocky summits where the larval foodplant *Castilleja* spp. grows. The thermoregulatory and territorial habits of this species are similar to the more northern genus *Euphydryas,* to which *T. fulvia* bears a superficial resemblance.

Dymasia dymas Edwards, 1877. 74292B5-6 upper Chorro Canyon.

This species of the Chihuahuan Desert and Tamaulipan shrubland is known to feed as larva on *Siphonoglossa pilosella.* Specimens taken in upper Chorro Canyon were all of the large light form *larunda* Strecker. Individuals of the typical form were seen in lower Chorro Canyon.

Phyciodes vesta Edwards, 1869. 73138D5 Rancho Madrid, 75162A4 chert gulch south of Middle Tank.

This species of dry washes in arid country and the subtropics utilizes *Siphonoglossa pilosella* as larval foodplant.

Phyciodes picta Edwards, 1865. 73138D6 Rancho Madrid, 74293B12-15 Rancho Madrid.

This species of the southern Great Plains (there is another race in the Sonoran Desert) occurs in grassy areas around seeps and along washes where *Aster* spp., the larval foodplants, grow.

Limenitis bredowii eulalia Doubleday, 1848. 73138F sight upper Chorro Madrid.

This large, spectacular, white-banded, black butterfly with orange-spotted wing apex occurs typically in oak woodland habitats of northern Mexico, mountains of the continental divide to Colorado, and the Edwards Plateau and Trans-Pecos ranges of Texas. Elsewhere, the larvae are known to eat various species of each of the three temperate American oak subgenera. In Chorro Canyon it may utilize *Quercus oblongifolia.* In the Davis Mountains *Q. hypoleucoides* is the presumed larval foodplant.

Asterocampa leila Edwards, 1874. 73138D7-8 Rancho Madrid, 73143A2 lower Tapado Canyon, 74291A1-6 lower Chorro Canyon, 74292B1 upper Chorro Canyon, 74293B7-10 & 11 (var.) Rancho Madrid, 75162B1 Lefthand Shutup.

This species is closely associated with the low shrubby growth of *Celtis pallida,* the larval foodplant. All specimens from this area are of the typical subspecies (described from the Sonoran Desert) rather than the south and central Texas subspecies *cocles* Lintner.

Asterocampa subpallida Barnes & McDunnough, 1913. 73142A1-2 Bofecillos Canyon.

This species previously was known only from the Sonoran Desert in the Santa Rita, Baboquivari, Huachuca, and Chiricahua Mountains of Arizona. Here it is associated with an old grove of *Celtis reticulata*, the presumed larval foodplant.

Family LIBYTHEIDAE

Libytheana carinenta mexicana Michener, 1943. 73138D10 Rancho Madrid, 73137A sight Log Spring Draw, 74293A2-3 lower Chorro Canyon, 74293B5-6 Rancho Madrid.

The larvae of this species feed on various species of *Celtis* and the adults are frequently seen roosting in thorn thickets along draws. Adults are often active at temperatures well over 38°C (100°F), when other butterflies have sought shaded refuge. After certain climatic events this species undergoes epidemic reproduction and adults migrate in great clouds both north and south out of the Chihuahuan Desert. All specimens taken appear to be this species rather than the very similar *L. bachmanii larvata* Strecker, which may also occur in the area.

Family LYCAENIDAE

Calephelis nemesis Edwards, 1871. 73143A sight lower Tapado Canyon, 74293B16-17 Rancho Madrid.

This metalmark is found at seeps along washes where its foodplants, *Baccharis* spp. and *Clematis* spp., grow.

Atlides halesus corcorani Gunder, 1934. 73137B6-7 Seep Springs summit.

Three individuals were defending territories on and around a large *Yucca thompsoniana* at the top of Seep Springs summit. Larval foodplants, the mistletoe *Phoradendron* spp., are uncommon in the area.

Strymon melinus franki Field, 1938. 73141H2-3 Tres Papalotes, 74292B10 upper Chorro Canyon, 75160A8 south slope Solitario Peak, 75161C5-9 Middle Tank.

This species is found around seeps; a couple were flushed from a fig bush at Tres Papalotes. The larval foodplants are diverse, mostly *Leguminosae, Malvaceae,* and *Rosaceae,* including 46 genera and 21 families.

Strymon new species. 73140D3-4 Gray's Ridge, 75159A13-17 ridge south of Tres Papalotes, 73137B sight Log Spring Draw.

This species was found hilltopping at two locations, visiting flowers of *Acacia greggii* and defending bush-top territories. It looks superficially like *Tmolus azia* Hewitson, but it is a *Strymon* spp. related to *S. melinus* and *S. rufofusca* Hewitson. Elsewhere it is known from southern Tamaulipas (Durden 70360A), probably from Big Bend National Park (specimens not seen), and possibly from Colorado (Boulder, Chataqua Mesa). In the Solitario it is associated with *Prunus havardii* thickets.

Brephidium exilis Boisduval, 1852. 75159A12 Tres Papalotes, 75160A11 gulch north of Solitario Peak, 75161C3 Middle Tank.

This species ranges throughout the Great Basin, Mexican Plateau, and arid regions of Texas, to the mouth of the Rio Grande. Larval foodplants include many common weeds such as *Atriplex bracteosa, Chenopodium album, Salicornia ambigua,* and *Petunia parviflora.*

Hemiargus isola alce Edwards, 1871. 73136C1-3 Righthand Shutup, 73137C1 Seep Springs, 73138A1-2 Smith Spring, 73138D11 Rancho Madrid, 73141H4 Tres Papalotes, 73142A8-9 Bofecillos Canyon, 73143A4 lower Tapado Canyon, 74292B7-9 upper Chorro Canyon, 74293A5 lower Chorro Canyon.

This species is frequent throughout the area and is often abundant at seeps, where it drinks interstitial water from wet silt. Foodplants of the mesquite blue include species of *Prosopis, Acacia, Albizzia, Indigofera, Melilotis, Desmanthus,* and *Dalea.*

Leptotes marina Reakirt, 1868. 73138D12 Rancho Madrid, 73141H5-7 Tres Papalotes, 73142A4-7 Bofecillos Canyon, 73143A5-6 lower Tapado Canyon, 75159A1 Tres Papalotes, 75162B2 Lefthand Shutup.

The marine blue congregates at seeps to drink on moist earth. The larval foodplants include species of *Astragalus, Plumbago, Dolichos, Galactia, Medicago, Phaseolus,* and *Lysiloma.*

Icaricia acomon texanus Goodpasture, 1973. 73143A3 lower Tapado Canyon, 75160A2 south slope Solitario Peak, 75161C4,10 Middle Tank.

Colonies of this species are very local and scattered in arid country and are associated with the larval foodplant *Eriogonum albertianum.*

Family HESPERIIDAE

Cogia hippalus Edwards, 1882. 73142A10-11 Bofecillos Canyon.

This species of Chihuahuan and Sonoran desert distribution, was found drinking at moist earth in the shade of cottonwood trees. The larval foodplant is unknown but related species utilize *Acacia* spp. and *Mimosa* spp.

Systasea zampa Edwards, 1876. 73143A7 lower Tapado Canyon.

This species of the Sonoran and Chihuahuan deserts flies along dry washes, where some of its larval foodplants grow. These are various species of Malvaceae.

Erynnis funeralis Scudder & Burgess, 1870. 73136A3 Solitario rim west of Solitario Peak, 74293A1 lower Chorro Canyon.

This widespread species of dry, disturbed open areas is quite variable in size. The unusually large October specimen from Chorro Canyon was found, upon dissection, to be this species. Known larval foodplants are species of *Lotus, Olneya, Robinia, Vicia, Indigofera, Geoffroca, Medicago,* and *Nemophila.*

Celotes limpia Burns, 1974. 75162A14 Fresno Peak.

This streaky skipper is endemic in West Texas and Coahuila. It is sympatric with the broader ranged *C. nessus* (Sonora to Oklahoma, Arizona to lower Rio Grande Valley). Both fly together at several localities and as larvae feed on various Malvaceae. *C. limpia* has been recorded as utilizing *Abutilon malacum, A. incanum, Sphaeralcea angustifolia* var. *lobata,* and *Wissadula holosericea.* In the Davis Mountains larvae of both species have been found on the same foodplant. *C. limpia* appears to occur at higher elevations and *C. nessus* at lower elevations beyond their zone of sympatry. Other records from this area are Kendall 29-31 August 1966, 1, 4-11, 17, 29 September 1966 on Ranch Road 170 15 mi SE of Redford (gulch west of Panther Canyon), and Lennox 26 March 1966, same locality.

Pyrgus communis Grote, 1872. 73143A sight lower Tapado Canyon, 75161C13 Middle Tank.

This species is widespread in disturbed areas where the larval foodplants grow. These are species of *Abutilon, Althea, Anoda, Callirhoe, Hibiscus, Malva, Sida, Sidalcea,* and *Sphaeralcea.* The single specimen is of the typical form but in the hot season the polymorphic var. *albescens* Plotz, differing in genitalic structure, is to be expected.

Copaeodes aurantiaca Hewitson, 1868. 73137C2-3 Seep Springs Draw, 73138C2 lower Chorro Canyon, 73140E1 Gray's Ridge gulch, 74292B11-12 upper Chorro Canyon, 74293A4 lower Chorro Canyon, 75160A10 gulch north of Solitario Peak, 75161C16 Middle Tank, 75161A1 south slope Solitario Peak.

This common orange skipperling is known to feed as larva on *Cynodon dactylon* elsewhere. Here it is associated with tall grasses in the heads of gulches and around springs.

Hesperia pahaska williamsi Lindsey, 1940. 73137B8 Seep Springs summit.

This skipper is found on high grasslands of Sonora, southern Arizona, Chihuahua, and western Texas. The foodplants are grasses.

Amblyscirtes oslari Skinner, 1899. 75161C2, 11, 12 Gray's Ridge gulch.

This is a species of bluff shrubland sites in prairie regions and ranges from Arizona to Saskatchewan, North Dakota, to North Central Texas (Baylor County). It is at the limits of its known distribution here. The single colony found in the Solitario is associated with the only pocket of *Quercus mohriana* (also a species of the southern plains) relict here. The life history is unknown, but the larval foodplants of its closest relatives are grasses.

Atrytonopsis ovinia edwardsi Barnes & McDunnough, 1916. 73138D13 Rancho Madrid.

This species was seen occasionally in the more rugged gulches of the Solitario. It ranges from Arizona to Coahuila (Serranias del Burro), and in Texas is known from the Guadalupe, Davis, and Chisos mountains, ranging south into Mexico.

REFERENCE CITED

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AN ARCHEOLOGICAL RECONNAISSANCE IN THE BOFECILLOS MOUNTAINS, PRESIDIO COUNTY, TEXAS

Barbara J. Baskin

INTRODUCTION

Several areas adjacent to the Bofecillos Mountains vent area have been investigated previously by the multidisciplinary group of the Natural Areas Survey Project of the University of Texas at Austin. In an attempt to gain insight into the complex interrelationships expressed through the archeological remains of the general area, the Bofecillos Mountains Survey was conducted in November, 1975, as a continuation of the previous Solitario and Fresno Canyon surveys (Hudson in press) and the Colorado Canyon Survey (Baskin in press). Located on the Diamond A Cattle Company Big Bend Ranch in southeastern Presidio County, Texas, the area included in the present Bofecillos Mountains survey is bordered on the north by the main east-west Big Bend ranch road, to the south by the northern extent of the Colorado Canyon survey area, to the east by a north-south ranch road from Sauceda Headquarters to the head of Madera Canyon, and to the west by the mouth of Bofecillos Canyon (Canyoncito) and the Redford Bolson (Fig. 1).

The primary purpose of this report is to present a descriptive summary and evaluation of the archeological significance of the 28 prehistoric sites located and recorded during this survey. Such a report will serve as a basis for future intensive reconnaissance, testing, and/or excavation of these nonrenewable archeological resources.

THE ENVIRONMENT

This section presents a cursory discussion of the present environment of the study area as it pertains to the archeological data. In depth information concerning the biology, botany, and geology of the area is contained in other sections of the report.

The Bofecillos Mountains survey area, which is within the Chihuahuan Desert biotic province (Blair 1950:105), is a semiarid to arid region which extends from the breached bolson* and gravel pediments of the Redford Bolson, northeasterly into the steepsided canyons of the fault-block zone which ascends into the rugged mountains and upland plateaus of the volcanic vent area.

According to the Thornwaite system of climate classification, the area is DB'd–semiarid, meso thermal, with a moisture deficiency during all seasons (Applegate and Hanselka unpublished MS). The mean annual maximum temperature from 1927 to 1968 was 86°F, the mean annual minimum was 53°F, and the mean annual temperature was 69°F. The mean annual rainfall for those same years was 8.24 in (Harris 1969:5). The period of mid-to-late summer and early autumn is considered to be the rainy season (McKnight 1970:2), at which time torrential rains often cause flash flooding in normally dry arroyos. Surface water occurs in the form of creeks or streams, seeps, springs, and tinajas (natural depressions in the bedrock which collect and hold water). All of the surveyed canyons evidence at least one intermittent water source, and several have perennial sources. The present amount of rainfall and occurrence of surface water is probably less than that of prehistoric times due to a continually drying climate and the lowering of the water table by modern man.

The flora of the area varies according to the geological and ecological setting but consists generally of arid-adaptive species. The fill of the Redford Bolson is dominated by creosote bush, yucca, ocotillo, and various cacti. The colluvial slopes and mesas of the canyons and mountains support lecheguilla, ocotillo, leather stem, cacti, and grasses, while the lower alluvial terraces are thick with mesquite, catclaw, creosote, soapbush, and cacti. Surrounding the spring areas of the canyons and upland plateaus are plants of the riparian association such as cottonwoods, baccharis, spiny hackberry, and desert willow. Historic documentation, with accounts of pastures of high-standing grasses and large stands of cottonwoods, pine, cedar, and oak, indicates that changing climatic conditions and use by man have severely altered the appearance of this area since prehistoric and early historic times (Applegate and Hanselka unpublished manuscript:23-24).

Applegate and Hanselka (unpublished manuscript)

*Bolson—a basin surrounded by mountains; drainage is toward the center terminating at a through-flowing stream that crosses the basin (Groat 1972:3).

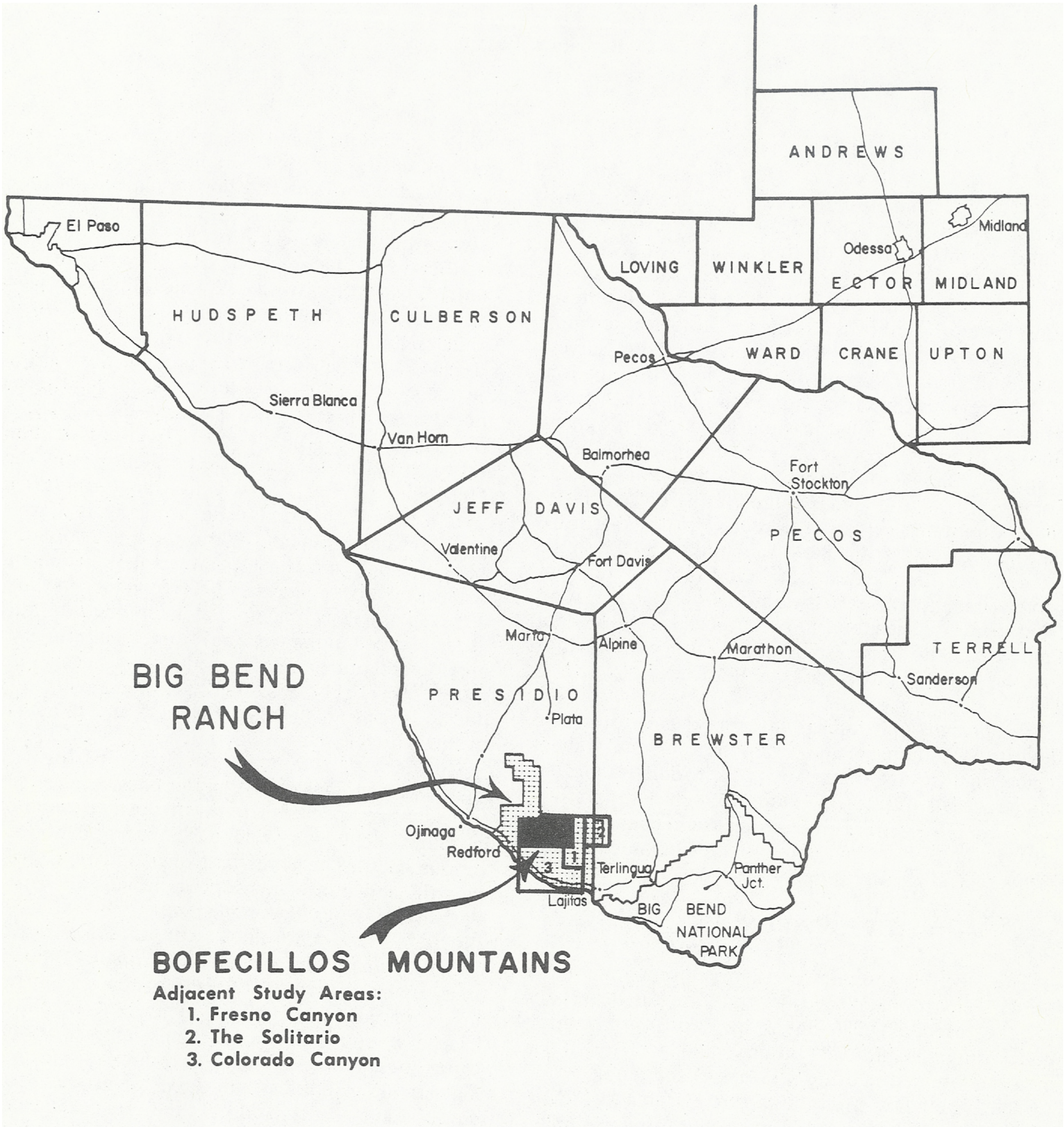

ANDREWS
El Paso
Midland
Odessa
LOVING
WINKLER
ECTOR
MIDLAND
HUDSPETH
CULBERSON
Pecos
WARD
CRANE
UPTON
Sierra Blanca
Van Horn
Balmorhea
Fort Stockton
JEFF DAVIS
PECOS
Valentine
Fort Davis
Marfa
Alpine
Marathon
TERRELL
Sanderson
BIG BEND RANCH
PRESIDIO
Plata
BREWSTER
Ojinaga
Redford
Terlingua
Panther Jct.
Lajitas
BIG BEND NATIONAL PARK
BOFECILLOS MOUNTAINS
Adjacent Study Areas:
1. Fresno Canyon
2. The Solitario
3. Colorado Canyon

Figure 1

present a list of 20 observed species of mammalian and arian fauna and a table of 38 species of reptiles and amphibians indigenous to the area (see Biology Section).

The Bofecillos Mountains were formed by volcanic activity during Tertiary times, followed by block faulting and later dissection which caused the high, rugged terrain of the main mountain system and the deep-cut, steep-sided canyons which drain the upland waters into the Rio Grande. Volcanic activity deposited "a varied sequence of lava flows, tuff, ash-flow tuff, and mudrock" (McKnight 1970:2). Subsequent erosion formed rock shelters which provided habitation areas for the prehistoric populations. The utilization of rock-shelters in various geologic formations, ecological situations, and topographical locations indicates the importance of protection from the natural elements in this harsh country.

Volcanism in the Bofecillos Mountains is also responsible for the igneous origin of the majority of the local lithics as confirmed by samples collected from archeological sites for lithic material type identification (see section entitled "Lithic Resources").

The possibility of finding well-stratified archeological sites in this region is slight because of the very thin soil deposits. Most of the northern portions of the surveyed canyons exhibit few, if any, terraces. The majority of those terraces observed are of low relative elevation and are still in an active state of alluviation and also subject to arroyo cutting. It appears that the general gradient of the canyons is too steep for alluvial deposition in the northern canyon area; however, a more gentle gradient becomes more conducive to alluviation nearer the mouths of these same canyons. Flat terraces* suitable for habitation were observed in the lower reaches of these canyons during the Colorado Canyon survey (Baskin in press). Most high benches** exhibit a greater slope which makes them undesirable for occupation. Also, benches higher in elevation above the streambed show an increase in size and density of colluvial rocks from natural talus slopes, whereas lower benches and terraces are covered with smaller colluvial gravels and alluvial gravels from drainage overflow and deposition, making them more desirable for occupation than the rockier areas.

In portions of the canyons where no terraces or benches are observed, vertical lava flow or volcanic tuff faces or steep slopes of loose, natural lava flow talus form the canyon walls (Fig. 2a, b, c). Only a few locations other than rock shelters and terraces are suitable for human habitation within these canyons.

Flowing southwesterly, Bofecillos Canyon varies physiographically from the other major tributary canyons which flow almost due southward. This canyon is not completely within the block-fault zone and, unlike the other canyons which are deep and steep-sided for nearly their full extents, Bofecillos Canyon contains areas where broad, relatively flat plains stretch for 0.2 to 0.4 km on either side of the drainage cut before they are enclosed by the steep mountains. The full length of Bofecillos Canyon has not been investigated, but the areas surveyed show a relatively high density of sites (Table 1).

The vegetation of the uplands does not vary greatly from that of the canyon slopes. The surface of most of the uplands is relatively flat with volcanic peaks protruding to heights of 5,000 ft. Smaller exposures of volcanic bedrock and lava flow float*** form rock shelters used for prehistoric occupation. Other areas of the uplands are very rough with volcanic rocks and boulders covering an undulating topography that is interspersed with dry arroyos. Very little time was spent in surveying the latter area, thus the sample indicated in comparison to sites within the canyons is probably not valid. It is possible that, although presently appearing dry and uninviting, this area was ecologically more inviting and offered a variety of available resources during prehistoric times.

ARCHEOLOGICAL BACKGROUND

Although summations have been presented on the previous archeological endeavors of this area and adjacent regions (Marmaduke and Whittsett 1975; Hudson in press; Baskin in press), a brief summary of pertinent data is provided below. Extensive discussion of the cultural traditions and their chronological sequence can be found in the following references: Sayles 1935; Kelley 1952, 1953; Shackleford 1950, 1955; Kelley, Campbell, and Lehmer 1940; Lehmer 1960; Campbell 1970; Story 1966.

Theoretical Background

Intermittent archeological work in the immediate Big Bend region of Trans-Pecos Texas was begun in the 1920s, but it was not until Frank M. Setzler (1935) attempted to include Trans-Pecos Texas under the Southwestern Pecos Classification System that intensive area research developed.

*terrace–relatively flat, horizontal or gently inclined surface of unconsolidated materials bounded by a steeper slope on one side and an ascending slope on the other (Lahee 1961:334).

**bench–denoting a geologic form like a terrace but in solid rock rather than unconsolidated material (Lahee 1961:334).

***float–rock separated from the parent strata or bedrock (American Geologic Institute 1962:185) (Fig. 3).

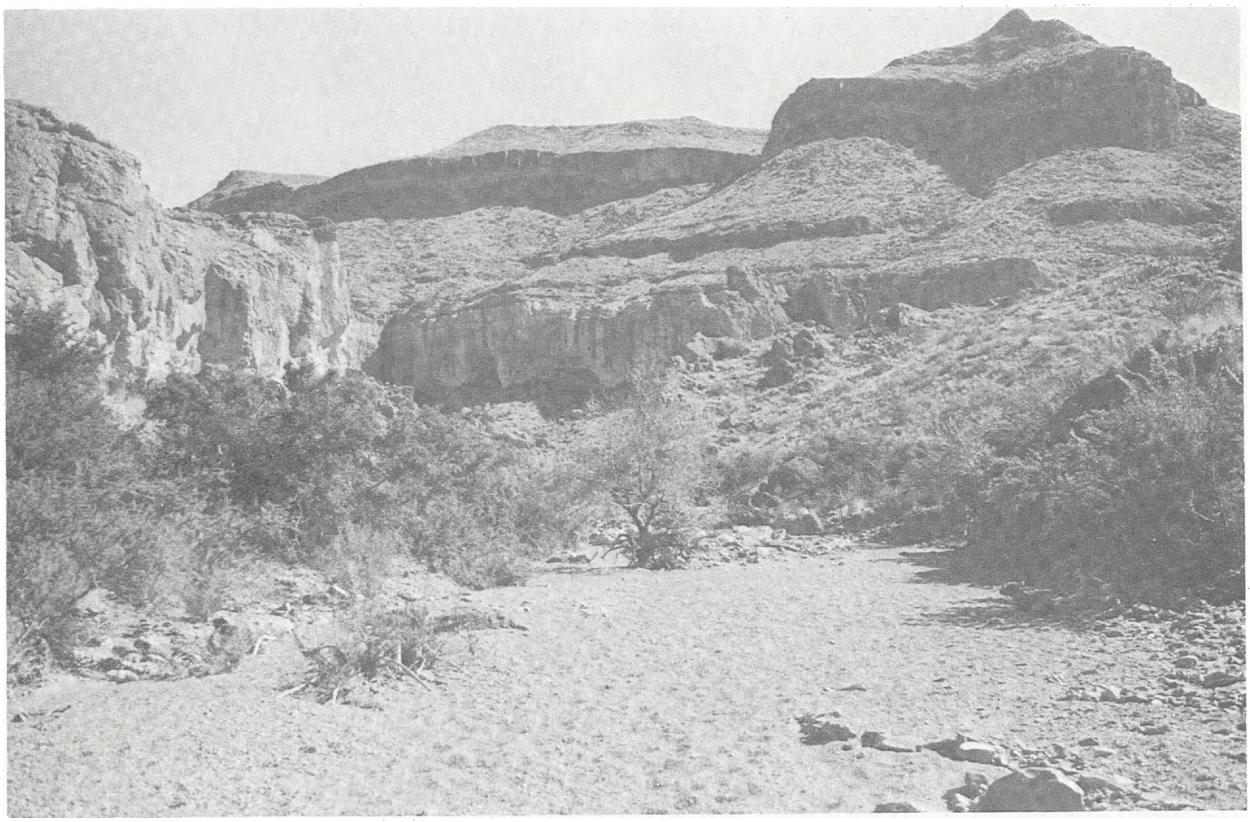
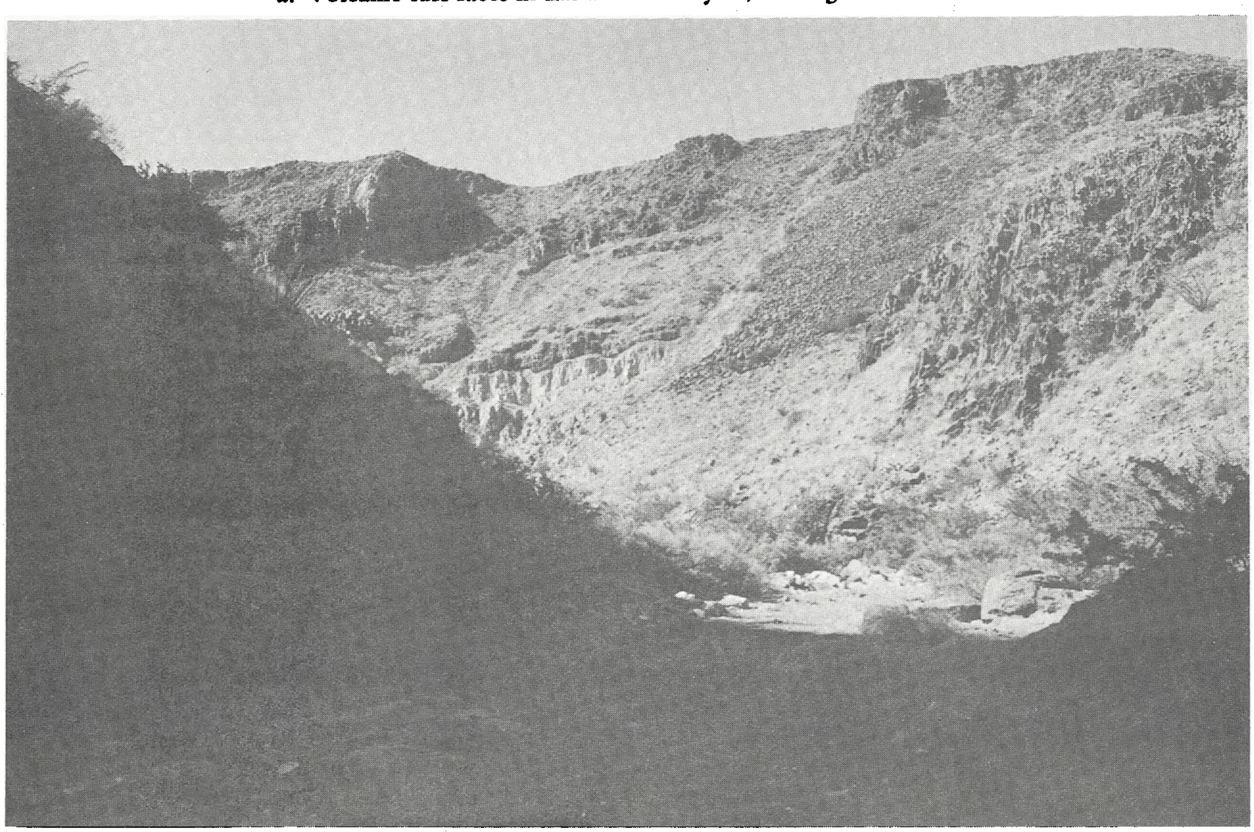


FIGURE 2

a. Volcanic tuff faces in Las Burras Canyon; looking northeast.



b. Natural lava flow talus slope in Auras Canyon; looking southwest.

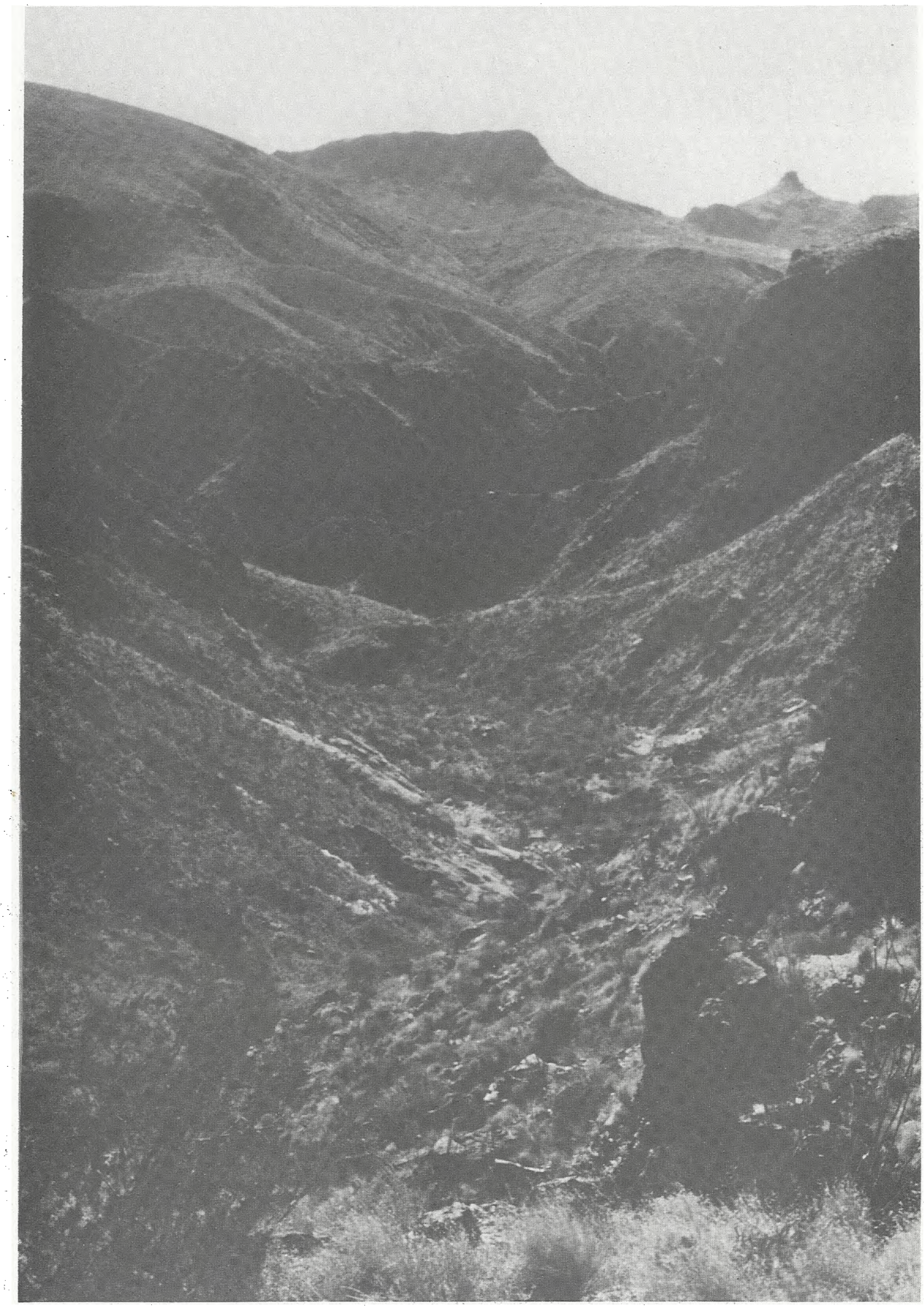


FIGURE 2

c. Looking south into Tapado (oso) Canyon.

Table 1: Site Provenience and Data

	Site Number	Location	Type of Site	Elevation	Landform	Distance from Water (Approx. Meters) Horizontal	Vertical	Area of Occupation (sq. meter)	Perishables	Cultural Debris Chipped Stone Artifacts	Chipped Stone Debitage	Ground Stone	Firecracked Rock	Cultural Features	Rock Art	Faunal Material	Present Condition
3	41 PS 174	Bofecillos Uplands	Open	1315	colluvial alluvial plateau	adjacent adjacent*	1m 1m*	7,000	No	Yes	Yes	No	Yes	hearths	No	No	partially eroded
2	41 PS 175	Las Burras Canyon	rock shelter	1200	tuff	100m 100m*	26m 26m*	300	No	Yes	Yes	No	Yes	midden deposit	No	No	partially eroded
2	41PS 176	Las Burras Canyon	rock shelter	1195	tuff	30m 30m*	15m 15m*	300	No	Yes	Yes	Yes	Yes	midden deposit	No	No	partially eroded
2	41 PS 177	Las Burras Canyon	rock shelter	1200	tuff	100m 100m*	13m 13m*	80	No	Yes	Yes	No	Yes	midden deposit	No	No	partially eroded
2	41 PS 178	Las Burras Canyon	rock shelter	1205	tuff	100m 100m*	20m 20m*	600	No	Yes	Yes	No	Yes	midden deposit	No	No	partially eroded
3	41 PS 179	Las Burras Canyon	open	1170	colluvial alluvial terrace	110m 110m*	13m 13m*	100	No	Yes	Yes	No	Yes	hearths	No	No	eroded
2	41 PS 180	Panther Canyon	rock shelter	1335	tuff	240m 240m*	160m 160m*	245	No	No	Yes	No	Yes	midden deposit	No	No	vandalized
2	41 PS 181	Panther Canyon	rock shelter	1255	tuff	10m 10m*	1m 1m*	166	No	Yes	Yes	Yes	Yes	midden deposit	No	No	intact
2	41 PS 182	Las Burras Canyon	rock shelter	1095	tuff	210m 210m*	146m 146m*	450	Yes	No	No	No	No	midden deposit	No	No	vandalized
2	41 PS 183	Las Burras Canyon	rock shelter	975	tuff	70m 70m*	26m 26m*	240	Yes	Yes	Yes	Yes	Yes	midden deposit	Yes	No	vandalized
2	41 PS 184	Las Burras Canyon	rock shelter	950	tuff and basalt	40m 40m*	13m 13m*	30	No	Yes	Yes	Yes	Yes	midden deposit	Yes	No	vandalized
2	41 PS 185	Las Burras Canyon	rock shelter	1025	tuff	10m 10m*	5m 5m*	15	Yes	No	No	No	No	midden deposit	No	No	partially disturbed
3	41 PS 186	Bofecilles Canyon	open	1160	alluvial	adjacent adjacent*	15m	12,500	No	Yes	Yes	Yes	Yes	midden deposit hearths	No	No	vandalized; eroded
2	41 PS 187	Bofecillos Canyon	rock shelter	1095	tuff	40m 40m*	15m 15m*	300	No	Yes	Yes	Yes	Yes	midden deposit	Yes	Yes	vandalized
2	41 PS 188	Auras Canyon	rock shelter	925	tuff	100m	40m	36	No	Yes	Yes	Yes	Yes	midden deposit	Yes	Yes	slightly disturbed
3	41 PS 189	Auras Canyon	open	1050	alluvial/ colluvial terrace	10m 10m*	5m 5m*	5,000	No	Yes	Yes	Yes	Yes	ring midden	No	No	partially eroded
2	41 PS 190	Auras Canyon	rock shelter	1160	lava flow	200m 200m*	180m 180m*	150	No	Yes	Yes	Yes	Yes	midden deposit	Yes	Yes	intact
2	41 PS 191	Auras Canyon	rock shelter	1195	tuff	100m 100m*	60m 60m*	3,750	Yes	Yes	Yes	Yes	Yes	midden deposit	Yes	No	vandalized
3	41 PS 192	Bofecillos Uplands	rock shelter/ open	1315	lava flow and plateau	250m 250m*	10m 10m*	625	No	Yes	Yes	Yes	Yes	ring midden	No	No	intact
2	41 PS 193	Las Burras Canyon	rock shelter	850	lava flow	20m	13m	20	No	Yes	Yes	No	Yes	none	No	No	intact
4	41 PS 194	Redford Bolson	open	815	colluvial/ alluvial Pleistocene Pediment	100m	50m	7,000	No	Yes	Yes	Yes	Yes	wickup rings	No	No	vandalized
2	41 PS 195	Bofecillos Uplands	rock shelter	1330	lava flow	140m 140m*	26m 26m*	300	No	Yes	Yes	Yes	Yes	midden deposit	No	No	intact
2	41 PS 196	Bofecillos Canyon	open	925	alluvial terrace	adjacent adjacent*	5m 5m*	3,750	No	Yes	Yes	Yes	Yes	midden deposit	No	No	partially eroded
3	41 PS 197	Bofecillos Canyon	open	950	colluvial/ tuff bench	40m 40m*	10m 10m*	300	No	Yes	Yes	Yes	Yes	midden deposit	No	No	partially eroded
2	41 PS 198	Bofecillos Canyon	open	960	bolson fill	120m 120m*	13m 13m*	10,000	No	Yes	Yes	No	No	none	No	No	partially eroded
2	41 PS 199	Bofecillos Canyon	open	1065	alluvial terrace	adjacent adjacent*	3m 3m*	10,000	No	Yes	Yes	Yes	Yes	ring middens	No	No	partially eroded
5	41 PS 200	Lava Canyon	rock shelter/ open	1275	lava flow and all/colluvial terrace	120m 120m*	26m 26m*	750	No	Yes	Yes	Yes	Yes	ring midden	No	No	partially eroded
5	41 PS 201	Bofecillos Canyon	rock shelter/ open	1095 to 1120	tuff bluff alluvial/coll terrace	adjacent to 300m same*	1m to 15m same*	240,000	No	Yes	Yes	Yes	Yes	midden deposit ring midden	Yes	No	partially eroded; vandalized

*Estimated Prehistoric.

FIGURE 3

Site 41PS 195; Rock shelter formed from a lava flow float boulder with cultural talus extending from the entrance.

Noting the uniqueness of the area and its archeological complexities, E. B. Sayles (1935) formulated an original chronological framework for this specific area, which, after further revision by Kelley, Campbell, and Lehmer (1940), has produced the cultural units presently in use.

The Archaic stage of development is represented by the Maravillas and Santiago cultures which are still poorly understood. However, the Pecos River and Chisos foci of the Big Bend Aspect (Campbell 1970:22) are widely represented. These Archaic components are interpreted as representing temporary camps utilized by small socio-cultural groups dependent upon a nonspecialized seasonal hunting and gathering economy. The latter part of the Chisos focus became minimally subject to a changing lifestyle initiated by contact with horticultural-ceramists from along the Rio Grande and upstream near El Paso.

The Livermore focus, temporally contemporaneous with the Late Chisos focus (Lehmer 1960:120), is based on a hunting economy and is thought to have influenced the development of the lithic tradition of the La Junta focus of the Bravo Valley Aspect (Kelley 1952:276). Peoples of the Livermore focus are also considered to be responsible for the introduction of the bow and arrow to southeastern Trans-Pecos (Lehmer 1960:125).

The Bravo Valley Aspect represents the Neo-American developmental stage in this region which followed after an emergence from the Archaic lifestyle. The acquisition of horticultural and ceramic-making techniques caused a change of lifeways which led to the emergence of a specialized local culture in and around the La Junta region, the general area of the confluence of the Rio Conchos and Rio Grande (Kelley 1952:227).

The La Junta focus (A.D. 1200-1400), representing the first cultural division of the Bravo Valley Aspect, shows an increasing dependence on agriculture. The later Concepcion focus (A.D. 1400-1700) differs from the previous focus only in ceramic and architectural styles, while the final cultural unit for the region, the Conchos focus (A.D. 1700-1800+), displays an acceptance and use of Spanish and European material goods.

Previous Fieldwork

The first areal surveys of the region were conducted in Big Bend National Park in 1936-37 by Erik K. Reed (MS 1936) and in 1937 by Paul R. Cook. Continuation of the Big Bend National Park survey was not again started until Dr. T. N. Campbell performed a reconnaissance during the summers of 1966 and 1967 under the auspices of the National Park Service (Campbell 1970).

To the west of Big Bend National Park, in both Brewster and Presidio counties, the University of Texas Natural Areas Survey Project conducted a preliminary reconnaissance of the Solitario and Fresno Canyon in June of 1975 (Hudson in press). Adjacent to this survey area is Chorro Canyon which was briefly investigated for the Texas General Land Office in 1973 by Liz Anderson (GLO Environmental Planning 1973). The Colorado Canyon Survey of 1975, also conducted by the Natural Areas Survey Project, investigated selected areas from Madera Canyon westward to the eastern edge of the Redford Bolson (Baskin in press).

Lands subject to disturbance by rechannelization of the Rio Grande near Ojinaja, Mexico, and Presidio, Texas, were investigated in December, 1973, and July, 1974, by the Texas Archeological Survey (Holliday and Ivey 1974).

The only archeological sites in the immediate vicinity which have been excavated are the Polvo Site (Shackleford 1951, 1955) at Redford, Texas, and Fort Leaton near Presidio, Texas (Ing 1971).

Pictographs and petroglyphs of the Big Bend region were first recorded during the 1930s by A. T. Jackson (1938) and later collections compiled by Forest Kirkland (Kirkland and Newcomb 1967). Miriam A. Lowrance of the Art Department of Sul Ross State University has continued with the compilation and study of the regional pictographs and has been the first to investigate the pictograph styles of the Bofecillos Mountains (Lowrance unpublished manuscript).

SURVEY TECHNIQUES

During the 12-day field reconnaissance conducted on foot by Barbara J. Baskin and Gary L. Moore, a total of 28 prehistoric archeological sites were recorded. For the purpose of this report, "site" is taken to imply any location at which occupation or other utilization by prehistoric peoples is evidenced by cultural features or debris.

Recording techniques included the plotting of all sites on 7.5-minute U.S.G.S. maps, photographs and sketch maps of all sites, and cross sections and frontal views of all shelter sites. In order to maintain a degree of standardization of the data for future comparative analysis and areal study, computerized State of Texas survey forms like those used for the previous Natural Area surveys were completed for each site. Due to the preliminary nature of this reconnissance, no surface artifacts were collected, and only a minimal sample of unidentified surface lithic debris was taken for analysis of material types.

Site designation numbers were issued according to the trinomial system used by the Texas Archeological Research Laboratory in Austin, Texas: 41 (Texas), PS (Presidio County), number (Xth recorded site in that county). All original field notes, survey forms, photographs, and maps are permanently housed with the Natural Areas Survey Project, University of Texas at Austin, and photocopies of survey forms and maps are on file at the Texas Archeological Research Laboratory, Austin, Texas.

Considering the large areal extent of the proposed Bofecillos Mountains Survey area, only a small portion of the total area could be systematically investigated in the given 12-day field period. Before entry into the field, the records of the Texas Archeological Research Laboratory at Austin were searched for previously recorded sites within the survey boundaries. Preliminary research of pertinent archeological reports and data from relevant disciplines, study of the area topographic maps, and preparation of a research design were undertaken.

Although no sites were found to be on file at Balcones Research Center in Austin, Texas, information on Site 41PS194 has been previously presented in a preliminary report by John L. Green of El Paso at the Texas Archeological Society convention in November, 1975. Many pictographs from some of the archeological sites of the area have been sketched and studied by Mrs. Miriam Lowrance of Alpine, Texas. Her notes and sketches and the help of her former assistant, Wayne Weimers (now with the U.S. Border Patrol), in relocating the sites greatly aided the reconnaissance.

The archeological reports of the previous area surveys (Campbell 1970; Marmaduke and Whitsett 1975; Lynn and Baskin 1975; Hudson in press; Baskin in press) indicate that the following types of sites could be expected: open alluvial and/or colluvial terrace sites; open upland plateau sites; open rim sites; and various rock shelter sites. These sites might show utilization for one or more of the following purposes: occupation (long-term or short-term); lithic tool production; quarrying or procurement of lithic materials; collection and/or processing of plants; killing and butchering of fauna. Some surface features and cultural debris expected to be observed included: hearths, thermally-altered stone, ring middens, midden deposit, cultural talus, smokeblack (in ceilings of shelters), lithic artifacts and debitage, perishables, ground stone artifacts, and pictographs.

The research design was prepared in order to yield the most valuable data for collating information from the Bofecillos Mountains survey and the previously surveyed areas of the Solitario, Fresno Canyon, and Colorado Canyon. As a continuation of these surveys, the following areas were designated for investigation: (1) the northern limits of Madera, Panther, Rancherias, and Tapado (Oso) canyons which were not completed during the Colorado Canyon survey; (2) the full extent of the main canyons of Las Burras, Auras, and Bofecillos Canyons, from the Redford Bolson into the highlands of the Bofecillos Mountains; (3) continual arbitrary "spot checking" of varying environmental and topographical areas within the survey bounds and recording of sites revealed by local informants; and (4) investigation of the southern portion of Lava Canyon.

Because of the severe time limitations for field reconnaissance, all phases of the research design were not completed. Only portions of Bofecillos Canyon were investigated, while none of Lava Canyon was surveyed. Approximately eight archeological sites described to the survey team by local informants were not recorded.

THE SITES

The 28 archeological sites recorded during the Bofecillos Mountains Survey show predominant prehistoric utilization, although historic reutilization is evidenced at some sites. The sites can be archeologically categorized as open sites, rock shelter sites, and associated rock shelter/open sites. Physiographically, the sites occur in the Redford Bolson, the major tributary canyons, and the uplands of the Bofecillos Mountains. Topographic locations show considerable locational variability, with sites being found on alluvial and/or colluvial stream terraces, colluvial upland flats, lava flow formations, and volcanic tuff formations. Because of the greater diversity of association under the physiographic and topographic categories, description and discussion of the sites are more aptly accomplished through use of archeological classifications (based on physical characteristics of sites). For comparative purposes, data pertaining to each specific site is presented in chart form (Table 1). General observations and descriptions of both typical and distinctive sites are provided in this section.

Of the 28 sites, 9 are open, 16 are rock shelters, and 3 are open sites associated with rock shelters. Seven open sites, 15 rock shelters, and 2 open/rock shelter sites are recorded from the surveyed areas within the major tributary canyons, while one site from each category is located in the Bofecillos uplands. The single site located within the general bounds of the Redford Bolson is an open site.

Condition of Sites

Relative inaccessibility of most portions of the survey area by the general public has helped, to a small degree, in protecting the sites from vandals and nondiscriminating relic collectors. Even so, one-third of all the recorded sites show signs of subsurface disturbance by man, and an unknown number have been collected of surface artifacts. Destructive occurrences by the natural elements have in some way affected all of the sites.

Open sites appear to be subject to a diversity of destructive factors. Due to the general sparcity of soil-stabilizing ground cover, erosion has affected all open sites to some degree. Those with sloping surfaces often show signs of gullying in addition to sheet erosion. Site 41PS186 and Site 41PS196 are excellent examples of loss of deposit due to sheet erosion, gullying, and subsequent downstream washing of midden soils (Fig. 4). Terrace cutting by flood stage water flow has also taken its toll of portions of several terrace sites (Fig. 5). Graded road cuts have disturbed or completely destroyed portions of Sites 41PS186 and 41PS201 (Fig. 18). In addition to destroying the cultural stratigraphy and enhancing natural erosion, these roads provide access to the sites which increases the likelihood of artifact collection by relic hunters. Reported rampant relic collection in previous years accounts, at least in part, for the general lack of surface artifacts. Surface observations reveal that this form of vandalism seriously affects the efforts of a reconnaissance of this type by skewing the actual artifact assemblage. Subsurface vandalism is observed at only one open site, 41PS194, where "potholes" have disturbed the center of several of the circular "wickiup" rings.

Rock shelter sites suffer less from natural destructive forces than do open sites; however, they are more susceptible to "pot hunting" because of excellent artifact preservation and ease in locating many of these protected cavities. Rodent activity in observed middens within rock shelters is minimal in light of the true destructive capabilities of rodents. The cultural talus in front of many of the rock shelters is subjected to all forms of erosion. In view of the fact that 9 of the 19 recorded rock shelters sites show evidence of subsurface vandalism, it is surprising that no blatant destruction of the associated pictographs was observed.

Open Sites

Of the nine open sites recorded in the survey area, seven are located in the canyons, one on the upland plateau, and one in the Redford Bolson. Because of the immense variation among the types of open sites, a general descriptive summary is not adequate and a temporary subclassification is needed. For descriptive purposes, open sites have been divided into two preliminary categories: probable habitation locales and resource collection and/or processing locales.

With the exceptions of Sites 41PS174 and 41PS194, all open habitation locales can be described in general terms using Site 41PS186 as a prototype. The four open habitation locales recorded within the major tributary canyons are situated on alluvial and/or colluvial stream terraces. These infrequent terraces provide relatively large, level areas within rugged canyons which generally offer few such locations. The sites are close to the canyon streambeds which presently provide intermittent water sources but which, in prehistoric times, may have provided more permanent water sources for aboriginal populations.

Site 41PS186 is situated on an alluvial terrace adjacent to the main drainage of Bofecillos Canyon at a perennial spring. Measuring approximately 12,500 square meters in horizontal extent, this represents the largest of the open habitation sites recorded. As indicated in the exposed terrace cut bank, its vertical depth is approximately 1 to 1.5 m. Typical of area terraces, the site is densely covered with mesquite, catclaw, allthorn, creosote, prickly pear, and cholla; however, in the streambed are stands of cottonwood, baccharis, and other riparian associated flora. A jeep trail cutting through the southern extent of the site and into the streambed has enhanced natural erosional gullying and caused loss of midden deposit and cultural debris, while indiscriminate looting by relic collectors is primarily responsible for the general paucity of diagnostic artifacts.

In addition to the thick midden deposit, the remaining surface indicators of prehistoric utilization are scattered fragments of thermally altered stone, lithic debitage, cores, and a few nondiagnostic unifacially and bifacially knapped tools. No grinding implements were observed on the terrace surface, although several bedrock mortars were found in the exposed tuff of the streambed.

The other three open habitation locales within the canyons (Sites 41PS179, 41PS196, 41PS197) are similar to the above description except that they are smaller in areal extent and have less vertical depth (50 cm or less). Numerical density of lithic and ground stone debris and artifacts is a variable factor dependent upon both length and intensity of prehistoric occupation and upon accessibility to the sites and intensity of relic collection.

Site 41PS174 differs from the other occupied terrace sites only in physiographical location. This site is located on a flat colluvial/alluvial plateau in the uplands of the Bofecillos Mountains, near a small east-west drainage leading into a steep entrance to Tapado (Oso) Canyon. This site appears to be entirely

FIGURE 4

Erosion of midden deposit and cultural debris at Site 41PS196 in Bofecillos (Canyoncito) Canyon.

FIGURE 5

Alluvial terrace Site 41PS196 showing effects of terrace cutting by flood stage drainage.

surficial (2-in deposit), with a few scattered hearth-like accumulations of thermally altered stone, lithic debitage, and nondiagnostic lithic tools.

The remaining open habitation site (41PS194) is located on a high Pleistocene terrace gravel pediment in the Redford Bolson (McKnight 1970:Plate 1). This important and unusual site consists of approximately 30 to 35 "wickiup rings" situated on a prominent terrace above the Rio Grande (Fig. 6). The term "wickiup" ring is used for lack of a more appropriate descriptive term as a designation for a circularly-stacked accumulation of rocks which form a base and support for a "rough hut covered with reed mats, grass, or brush wood" (Webster 1973:1339).

The rings are formed of small (ca. 30 cm diameter), naturally occurring lava flow boulders situated in a circular shape and piled to a height of approximately 25 to 40 cm. The bases of some of the boulders have been partially buried by more recent deposition and several of the rings exhibit well-defined entranceways which generally open toward the Rio Grande (south). These rings vary slightly in size but, on the average, are 3 m in diameter. "Pot holes" in the center of several of the rings indicate that the cultural fill may be as much as 50 cm in depth. The site has been looted of surface artifacts and no diagnostic materials were observed by the survey team. Remaining surface material consists of lithic debitage (mainly displaying unifacial retouching), many manos (although metates are virtually absent), a small amount of thermally altered rock, and several well-defined hearths. The lithic material types observed from the surface debitage indicate utilization of both river cobbles and lithics from upland sources. This site is only three miles upstream from Site 41PS124, a "wickiup" ring site located during the Colorado Canyon Survey (Baskin in press).

Located within two of the major tributary canyons, the open resource collection and/or processing locales include two terrace sites with ring middens and one lithic resource procurement and quarry area. The exceptionally large ring midden at Site 41PS189 is located on an alluvial terrace at the confluence of two major side canyons of Auras Canyon (Fig. 7a and b). Surface observations indicate that the ring midden does not form a complete circle of thermally altered stone but exhibits a high side or crest on the downwind side (northeast) of the present prevailing wind (southwest). Burned rock forms a crescent approximately 3 m in width, with a relatively rock-free interior depression ("pit") measuring approximately 7 m in diameter. A pile of burned rock (ca. 9^2m) opposes the crest of the ring on the opposite side of the depression. The main body of the midden appears to be intact although only a few fragments of ground stone, lithic debitage, and nondiagnostic lithic implements was observed.

Site 41PS198 is located at the base of a large cliff of undifferentiated tuff, sandstone, and conglomerate on colluvial bolson fill of the same composition (McKnight 1970:Plate 1) (Fig. 8). Surface observations indicate both aboriginal collection of surface cobbles and quarrying of cobbles embedded in the tuff agglomerate. Rhyolite is the only raw lithic material type found at this location. Exhausted cores and rejected blades constitute the main body of the debitage. A lack of secondary retouched flakes seems to indicate that blades were being removed from cores, and selected blades were then being taken elsewhere for further refinement.

Rock Shelter Sites

Of the recorded rock shelter sites, 15 are located in the canyons and one in the uplands. All rock shelters are formed in either dark lava flows or light-colored tuff or tuff agglomerate formations. The major variations among rock shelters is evidenced through density of the cultural deposit and elevations relative to the streambeds. All but one of the rock shelters display some midden deposit, and several evidence thick cultural talus deposits extending downslope 10 to 50 m (Fig. 9). The majority of the shelters are within 50 m horizontal distance to the canyon streambottom, which is presently an intermittent water source but which may have been a perennial source during prehistoric times. Vertical elevation of occupied rock shelters varies from 1 to 180 m above the streambed. This inconsistency can be attributed to the highly variable natural location of these rock shelters. The size of the actual shelter cavities ranges from 6^2 m (4 m in width, 1.5 m depth, 1.8 m height) to 56^2 m (14 m width, 4 m depth, 3 m height). The entire site area of the rock shelter sites is also quite variable and ranges from 20^2 m with no associated cultural deposit to $5{,}000^2$ m with cultural talus included.

Cultural indicators observed at the rock shelters do not show significant variation. Thermally altered stone, midden deposit, lithic debitage, unifacial and bifacial lithic tools, and ground stone artifacts are common at most of the sites. Other less frequently observed cultural remains include pictographs, perishables such as quids, faunal remains such as animal bones and mussel shell. Many of the shelters have large, dense cultural talus slopes of burned rock, ash, midden deposit, and lithic debris.

Site 41PS181 is located in dark-colored lava flow at a low relative elevation in Panther Canyon approximately 100 m upstream from a perennial spring (Panther Springs). Although only 1 m (vertical) above

FIGURE 6

"Wickiup" ring, with entranceway, at Site 41PS194 located on a Pleistocene terrace gravel pediment overlooking the Rio Grande to the south. Photograph is looking north with Bofecillos Mountains in background.

FIGURE 7

a & b. Ring midden at Site 41PS189 located on an alluvial terrace at the confluence of two main side canyons of Auras Canyon; looking northeast.

FIGURE 8

Quarry site, 41PS198, situated on colluvial bolson fill. Rhyolite cobbles were procured from the surface and also quarried from a formation of undifferentiated tuff, sandstone, and conglomerate. Looking northeast.

FIGURE 9

Dense cultural talus slope extending from the rock shelter at Site 41PS177 in Las Burras Canyon. Looking north.

the streambed, the midden deposit does not appear to have been scoured by flood waters (Fig. 10). The actual shelter is 14 m in width, 4 m in depth, and 3 m in height, with a midden deposit estimated to be 50 cm in depth. The midden and small talus deposit extending from the mouth of the rock shelter reveal one basin metate of lava flow, lithic debitage, and bifacially and unifacially worked nondiagnostic lithic implements. The intensive smoke-blackened ceiling is in part attributed to recent use, and the small rock wall at the north end is known to be the work of a student of the 1974 Outward Bound School who lived in the shelter for three days.

In contrast to the low relative elevation of Site 41PS181, Site 41PS190 is situated approximately 180 m above the streambed of Auras drainage in a vertical lava flow above a 45° slope covered with both natural lava flow talus and a cultural talus midden (Fig. 11). The rock shelter cavity is 4 m from dripline to backwall, 12 m in width, and 3.5 m in height, and the dense cultural talus extends 40 to 50 m downslope with an estimated depth of 2.5 m.

An abundance of lithic debitage, chronologically nondiagnostic tools (bifaces, unifaces, scrapers, retouched flakes) and many grinding implements was observed. One freshwater mussel shell was collected from the cultural talus of burned rock, lithics, and ash and midden deposit. This type of cultural debris and the density of the cultural talus might indicate aboriginal plant processing activities at this site. A small, "donut-shaped" pictograph of red pigment is centered above the entrance of the rock shelter (Fig. 11), and more pictographs, not visible at the time of the survey, have been reported (Miriam Lowrance, personal communication). The ceiling of the shelter has some smoke-blackening but is also darkened by fungi and natural asphaltum. The shelter thus far shows no signs of vandalism.

Located in a comparatively broad portion of Auras Canyon at the base of a high vertical formation of light-colored tuff (Cuevas Amarillas Tuff), Site 41PS191 is more precisely a wet overhang (slight overhang offering some protection but allowing moisture to contaminate deposit) rather than a rock shelter (Fig. 12); however, the numerous spalled tuff boulders at the base of the bluff indicate the possibility of the existence of a more protective overhang in prehistoric or early historic times. The midden deposit at this site extends approximately 75 m along the base of the pictograph-bearing tuff face. The cultural talus extends 40 m downslope with a maximum vertical depth of deposit estimated at 1 m. The site is situated approximately 60 m above Auras streambed, and an intermittent spring flows out of the moss-covered tuff to the east of the site. An abundance of lithic debitage and several manos, metates, and bedrock mortars compose the ground surface cultural assemblage.

The tuff face is literally covered with pictographs of red, black, and yellow pigments (Fig. 13), and pictographs on the tuff spall indicate that the majority of the face may once have been more densely covered with these paintings. The images range from abstract geometric designs to depictions of life-like forms. Several pictographs realistically resembling a human figure riding a four-legged animal (Fig. 14) evidence shelter utilization, at least for the purpose of picture-writing, during the post-European/Spanish contact period. Prior and subsequent occupations may and probably have occurred. Pictographs need not necessarily correspond temporally to any of the midden layers, although cultural association with at least one stratigraphic component is probable.

Rock Shelter/Open Sites

The final archeological classification is comprised of three sites which consist of both rock shelters and an open site area with surface cultural features. To avoid confusion, dense cultural talus in front of rock shelters is differientiated from a well-defined ring midden in front of or near a rock shelter. Two of the rock shelter/open sites are situated adjacent to the drainages of Bofecillos and Lava Canyon in proximity to the main east-west ranch road. The remaining rock shelter/open site is in the uplands of the Bofecillos Mountains near a dry, unnamed arroyo.

Site 41PS192 is an excellent example of an open ring midden site situated directly in front of a small lava flow float rock shelter (Fig. 15). The rock shelter is approximately 10 m in width, 1.5 m in depth, and approximately 2 m in height with a midden fill of approximately 1 m. The accompanying ring midden extends from the dripline of the rock shelter south for ca. 25 m. The interior depression or "pit" is well defined and the estimated 2.5 m of deposit appears to be intact with no disturbances. Surface debris is similar to that found at other ring middens and rock shelter sites with lithic debitage, nondiagnostic lithic tools, a few ground stone fragments and thermally altered stone composing the bulk of the cultural debris. Possibilities for recovery of pollen samples for analysis are eliminated because of contamination by dense creosote bush coverage on the ring midden. With the exception of the ring midden being positioned on a terrace approximately 30 m from the base of the talus slope rather than directly adjacent to the dripline of the rock shelter, Site 41PS200 corresponds to the above description of Site 41PS192.

Site 41PS201, known locally as Las Cuevas Amarillas (Yellow Caves), has the greatest horizontal

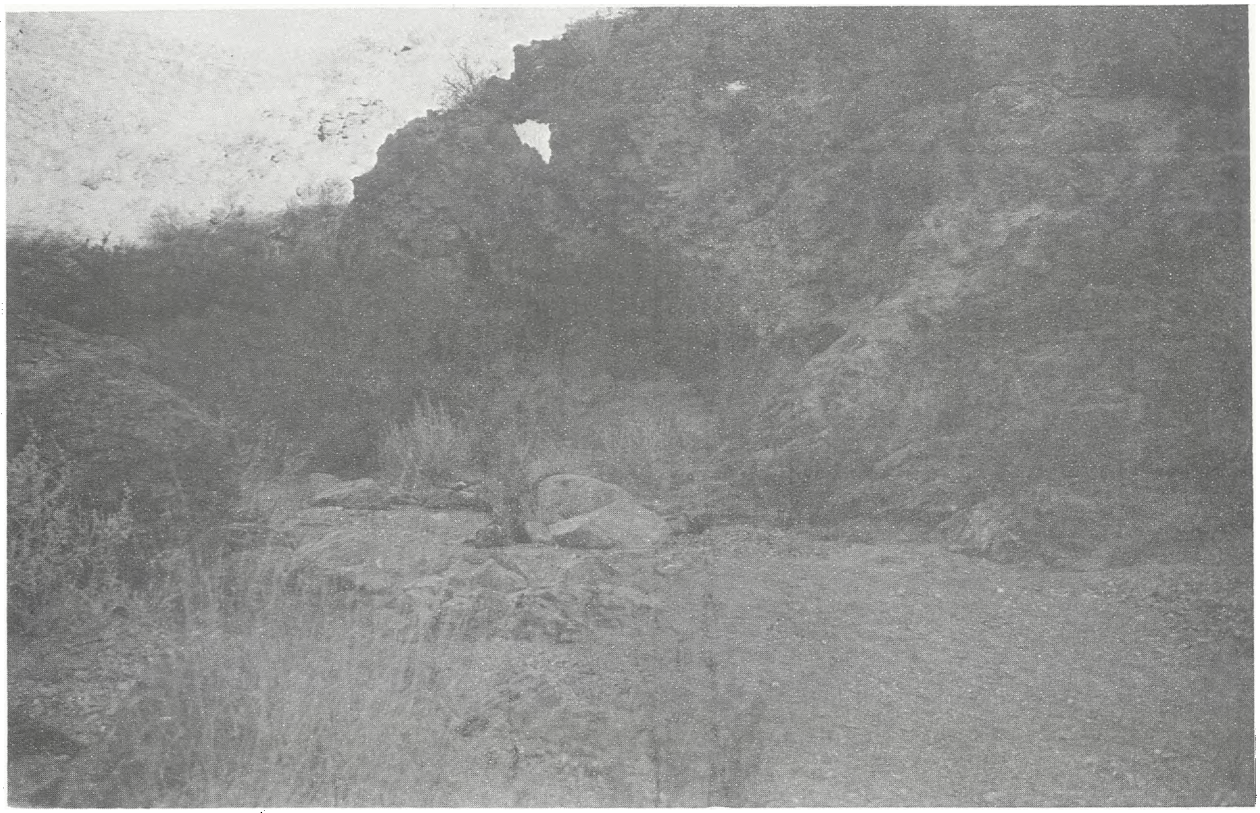
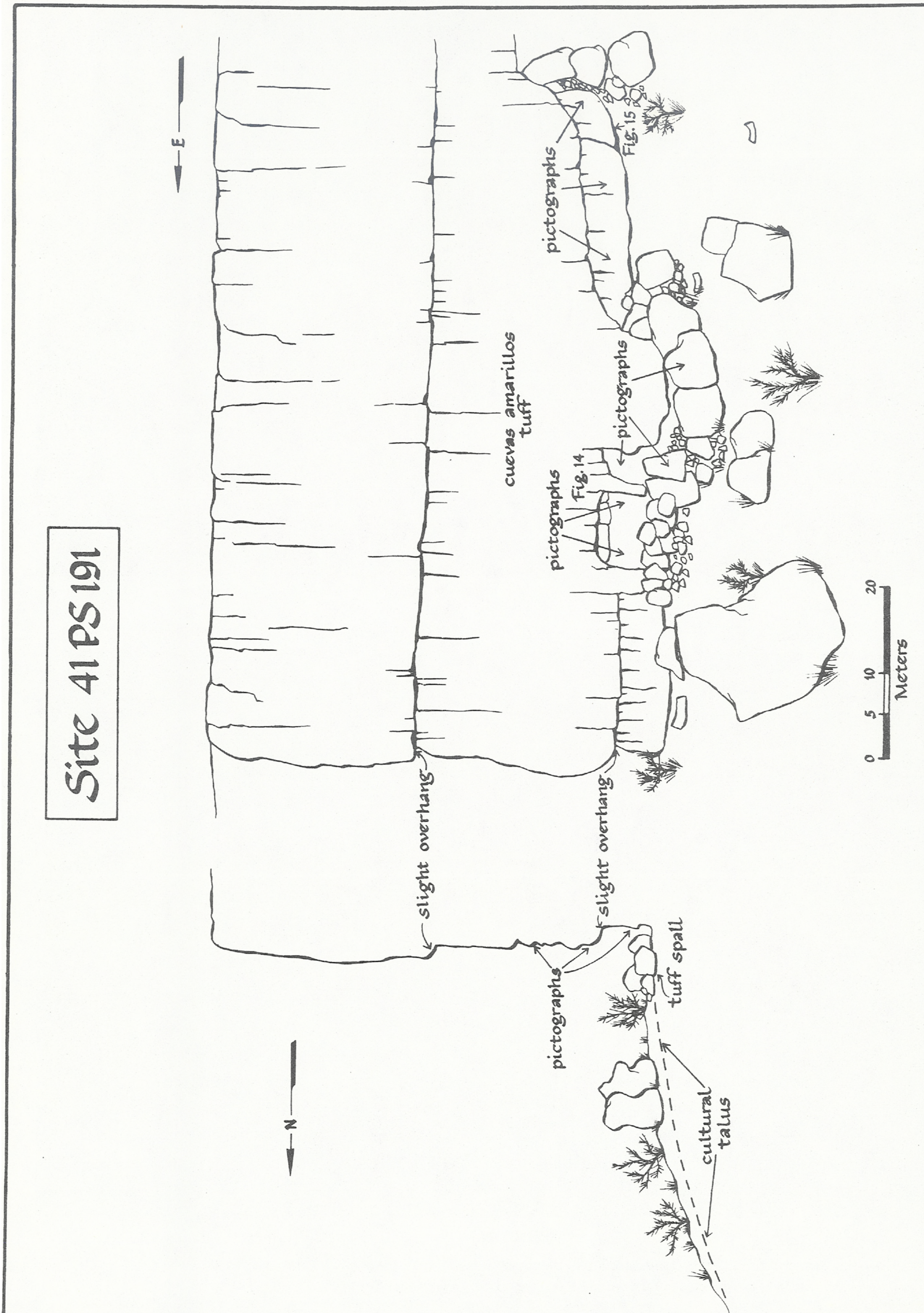


FIGURE 10

Rockshelter site, 41PS181, situated at a low relative elevation in Panther Canyon.

FIGURE 11

Rockshelter site, 41PS190, situated 180 m above streambed in Auras Canyon, with a cultural talus extending ca. 50 m downslope. Note small red pictograph above entrance of the shelter.



Site 41 PS 191
E
N
slight overhang
slight overhang
cuevas amarillos tuff
pictographs
pictographs
pictographs
pictographs
pictographs
pictographs
Fig. 14
Fig. 15
tuff spall
cultural talus
0 5 10 20
Meters

Figure 12

FIGURE 13

A portion of tuff face at Site 41PS191 bearing many pictographs of black, red, and yellow pigment.

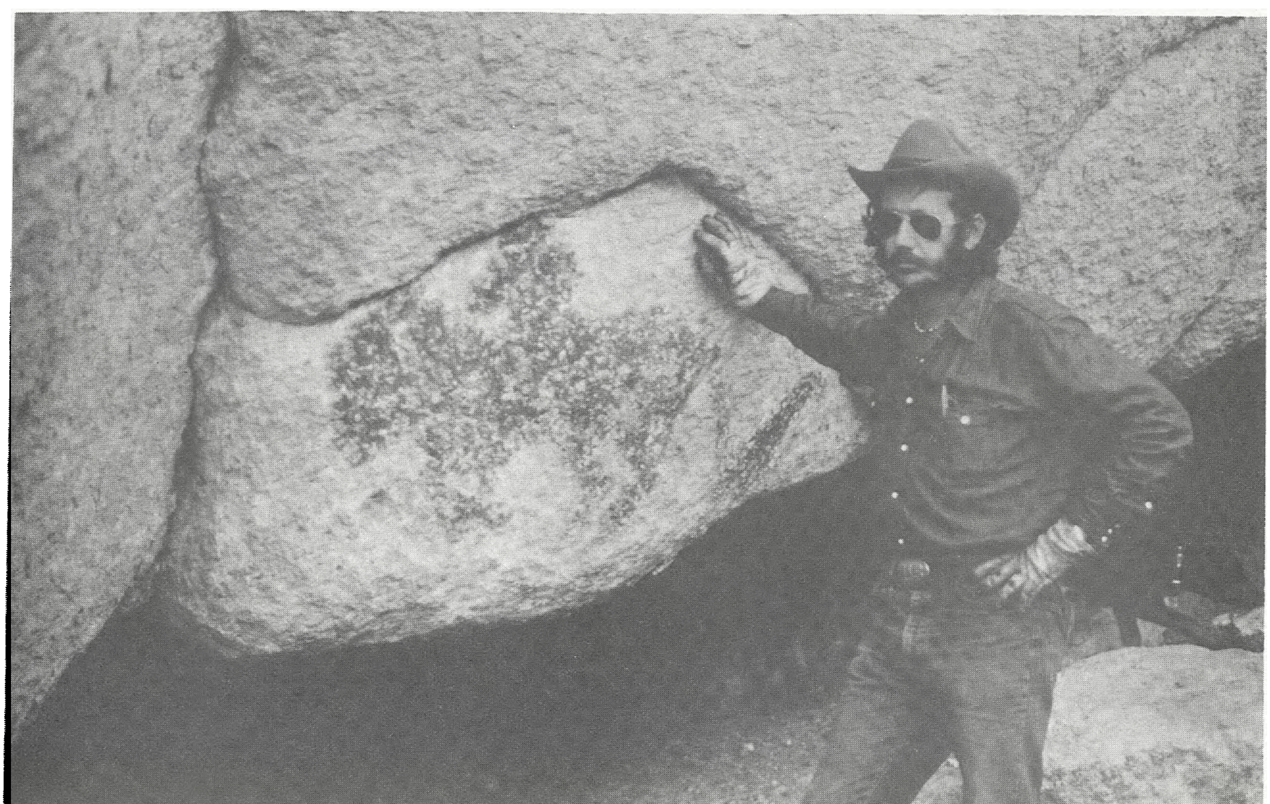


FIGURE 14

Pictograph (black pigment) of a mounted human figure at Site 41PS 191 indicating a post-European contact time period.

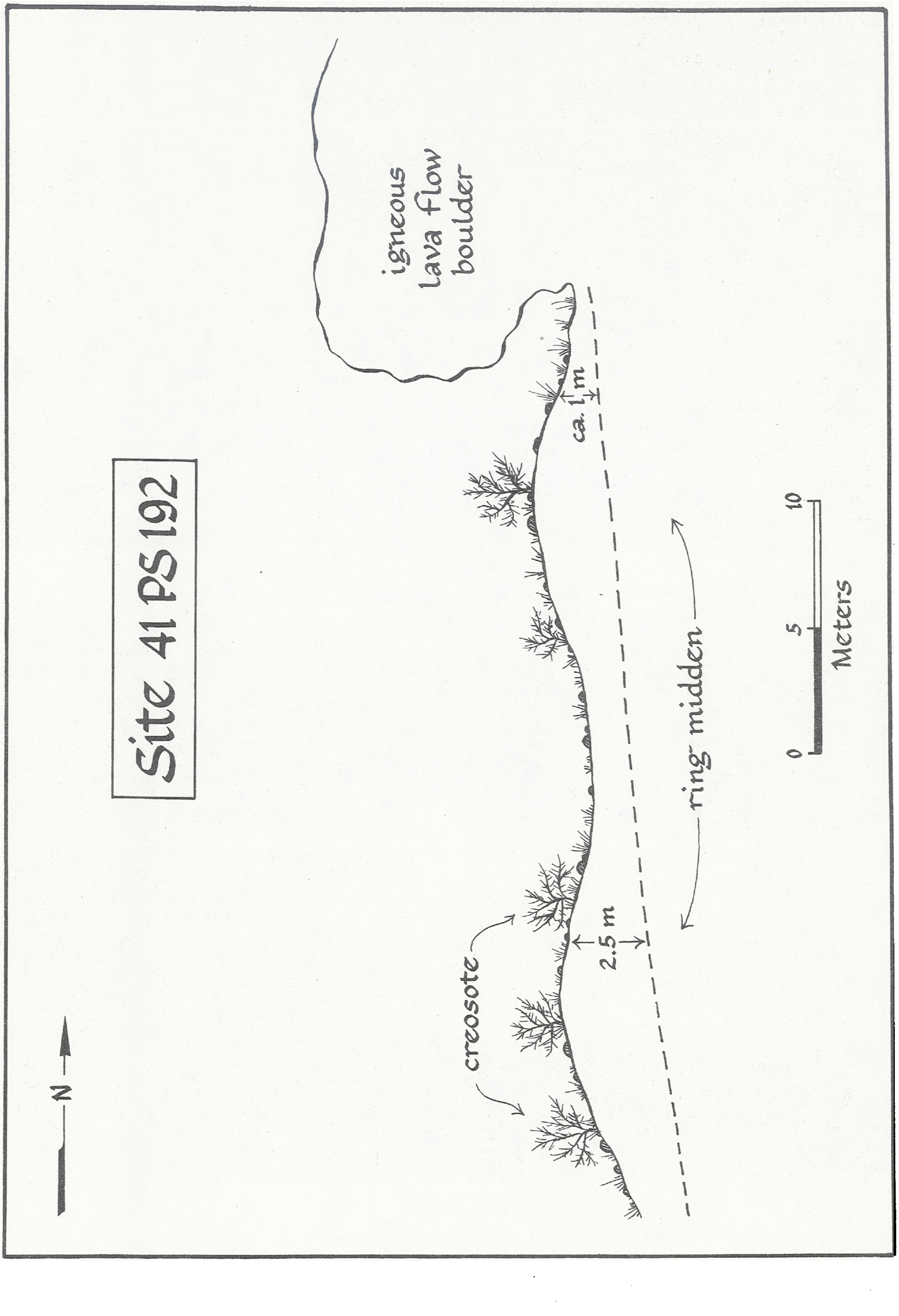

Site 41 PS 192
N
igneous lava flow boulder
ca. 1 m
creosote
2.5 m
ring midden
0
5
10
Meters

Figure 15

extent of the recorded sites and, from its vertical depth, appears to represent one of the more intensely occupied sites. Located around a prominent exposure of light-colored tuff (Cuevas Amarillas Tuff) on the valley plain and terrace of the Bofecillos Canyon drainage, the site consists of an open occupation area and associated rock shelters (Fig. 16). Creosote, catclaw, and various cacti predominate the open site area while little vegetation grows on the tuff exposure. Along the terraces and streambed of the adjacent drainage are catclaw, mesquite, and flora of the riparian association (i.e., cottonwood, bacchariss, etc.). The large dense midden deposit covers approximately 240,0002 m and shows an abundance of lithic debitage and nondiagnostic tools and slab and bedrock metates and mortar holes. Several possible ring middens were observed in the very dense undergrowth along the banks of the drainage south of the ranch road. The rock shelters of the site occur primarily in two tuff formations. The main exposure, to the north of the road, contains many small cavities formed by wind and solution high on the face and upper surface of the formation, and larger rock shelters at ground level around the base of the tuff. Some of the smaller shelters show no evidence of occupation, but most of the larger cavities and overhangs exhibit at least some smoke-blackening on the ceiling. The three long shelters in the smaller tuff formation to the south of the road (Fig. 17) exhibit deep bedrock mortars, smoke-black, and a talus midden through which the road cuts. The pictographs and handprints which occur in both of the tuff areas are mainly of red and black pigments. Although the site has been extremely disturbed by the road cut and vandalized of surface and subsurface materials, this remains an important site warranting testing and excavation because of its horizontal extent and the density of the cultural deposit.

UTILIZED LITHIC MATERIAL TYPE ANALYSIS

Identification of lithic material types in the Bofecillos Mountains is difficult due to the geologic complexity of this volcanic vent area and the subsequent alteration of many local rocks from their original state. The collected lithic samples were identified by Cader Shelby of the Texas Water Development Board and Ed Garner of the Bureau of Economic Geology, Austin, Texas. A general classification of the material types is necessary, because limited project funds preclude positive identification by thin section analysis.

The majority of the worked lithics can be lumped under the general classification of "silicified" rock (Cader Shelby, Dwight Deal, Ed Garner 1976:personal communication). Further separation into "silicified volcanic" or "silicified sedimentary" is difficult unless microfossils or phenocrysts and/or shards are observed in the aphanitic to fine-grained mass (Shelby and Garner 1976:personal communication). Rocks of similar or identical mineral composition may appear very different visually, whereas mineralogically different rocks may appear similar to the unaided eye, depending on such factors as color, crystal size, texture, amount of silicon replacement, and degree of alteration from the original state (Shelby and Garner 1976:personal communication). The classification of glossy, opaque silicified rocks under the general term "chert" and glossy, translucent silicified rocks as "chalcedonic chert" is necessary. The "chert" and "chalcedonic cherts" observed on the archeological sites range in color from white to tans, browns, reds, grays, and multicolors. Aphanitic to fine-grained in texture, they have a glossy to vitreous luster and fracture conchoidially, with favorable chipping characteristics for tool manufacture. The majority of flakes and implements made of these siliceous rocks are fairly small in size (less than 5 cm), suggesting that the source material may also have been small in size or naturally fractured so that only small debitage was produced.

Cretaceous sedimentary chert, common in most of the Solitario area to the east, is not common in the Bofecillos Mountains, as is indicated by the area geologic map (McKnight 1970:Plate 1). The true sedimentary chert is not to be confused with local "chert" formed as a precipitate of the excess silica in the groundwater and deposited in voids within the igneous rocks in the Bofecillos Mountains (Shelby and Garner 1976: personal communication). The only known location in the Bofecillos Mountains which may yield sedimentary limestone cherts as well as replacement cherts is Rancherias Dome (McKnight 1970:Plate 1). Rancherias Dome is an eroded valley with upper Fresno and Rawls lava flows overlaying Cretaceous strata of the Pen Formation (gypsiferous, calcareous clay), the Boquillas Formation (interbedded, flaggy limestone and clay), Undiffereniated Comanche Limestone (massive micritic limestone, partly contact metamorphosed to marble and skarn), and veins of Chalcedonic Silica (fissure veins and replacement deposits) (McKnight 1970:24, Plate 1). Other than Rancherias Dome, the closest known limestone exposures are approximately 16 km to the east, on the western edge of the Solitario. For this reason (unique location) and because of the adjacent location of seven terrace gravel pediments (favored areas for prehistoric site locations), it is very possible that Rancherias Dome might have been a major quarry area for prehistoric inhabitants and an investigation

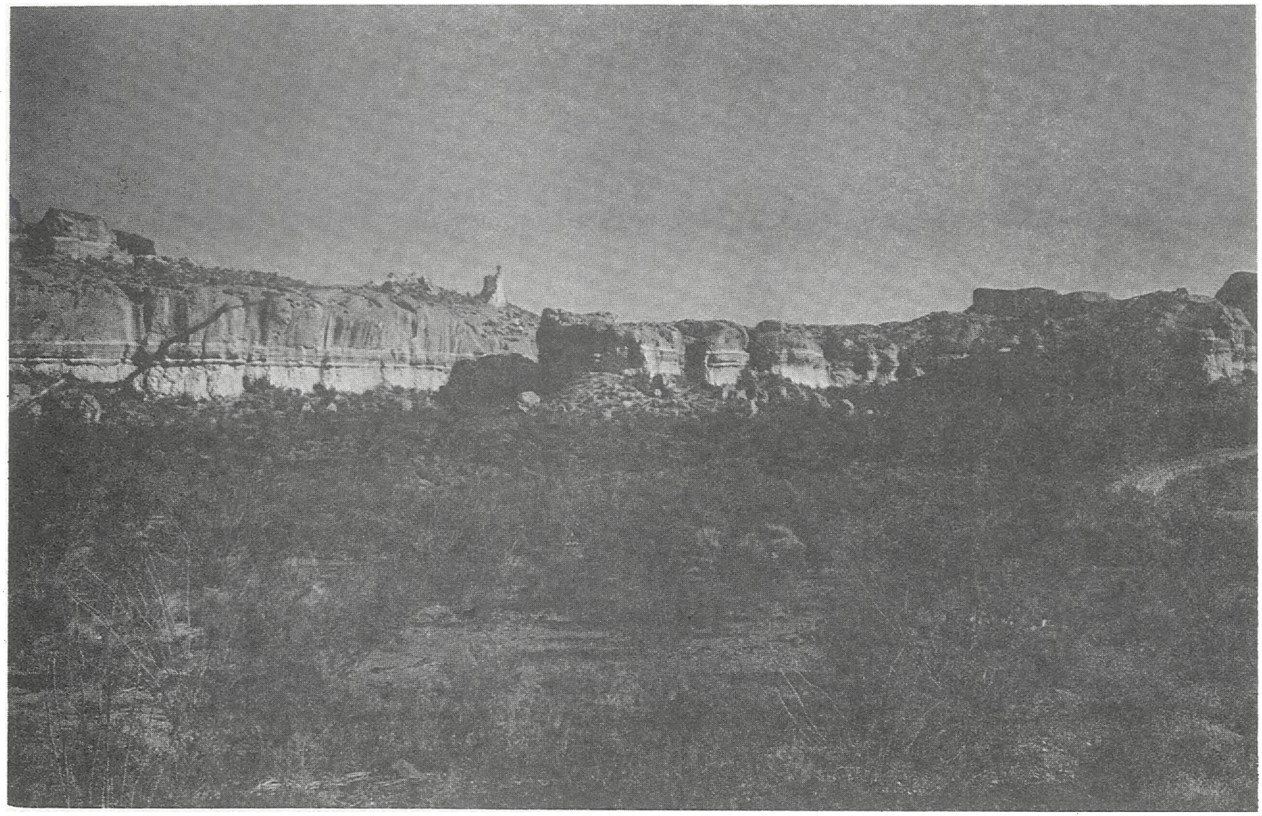


FIGURE 16

Large tuff formation extending onto the plain adjacent to Bofecillos Canyon drainage. Some small cavities in the tuff show evidence of occupation and the open site area extends along the base of the formation.

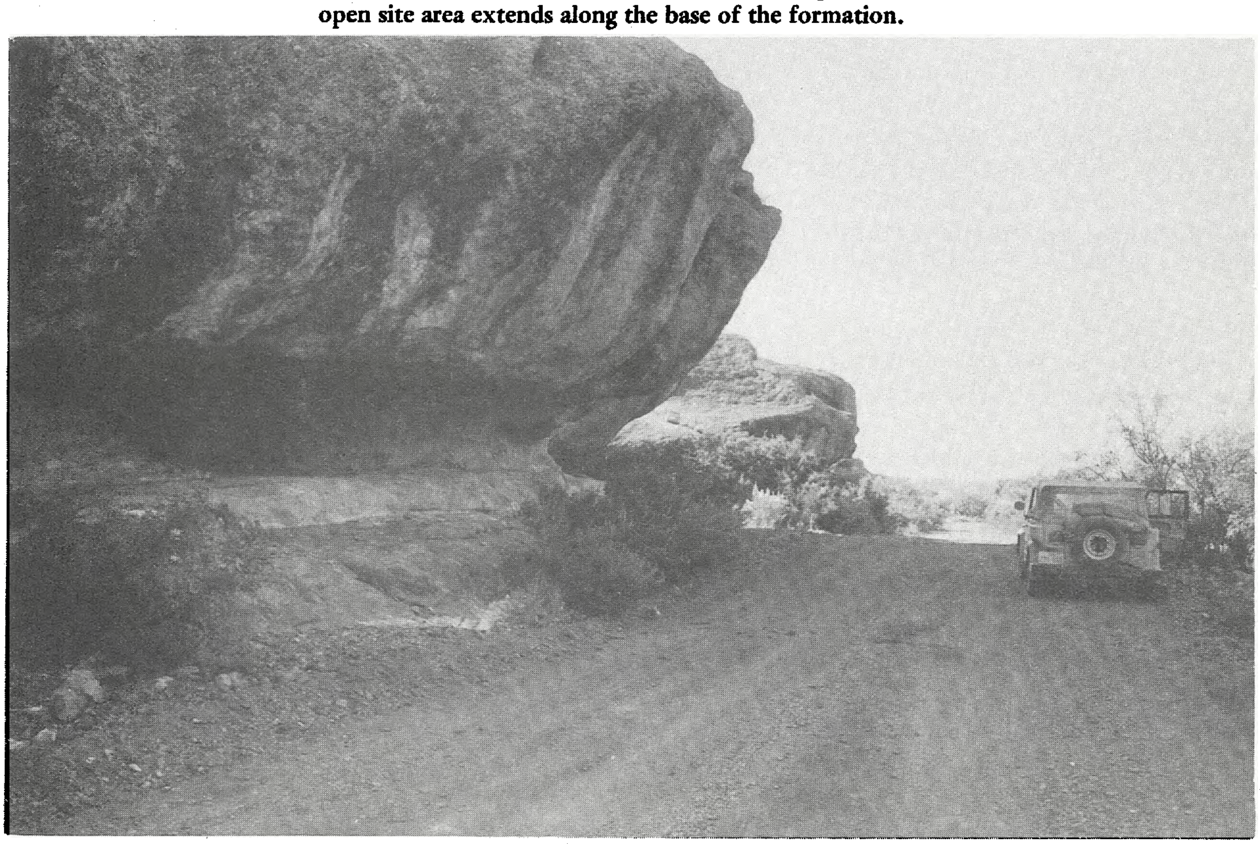


FIGURE 17

Rockshelters in tuff formation at Site 41PS201, Las Cuevas Amarillas, with main ranch road cutting through the dense midden deposit. Looking west.

of this area should be made.

The nonsilicified, light-colored igneous rocks, which are aphanitic to fine-grained in texture, have been lumped into the general category of felsite (Pearl 1955:185; American Geologic Institute 1962:177; Cader Shelby 1976:personal communication). Rhyolite is observed on all of the sites and appears to rank second to silicified rocks as a favored material type utilized for tool manufacture. Feldspar, is observable, along with quartz, as phenocrysts in the aphanitic to fine-grained mass of the local rhyolites (Garner and Shelby 1976:personal communication). Some silicified rhyolite with faint phenocrysts still embedded is observed, but by the present definition is classified under "silicified" rocks. Rhyolite and other felsites occur mainly in lava flows and are abundant throughout the Bofecillos Mountains and also as river cobbles along the Rio Grande from volcanic areas upstream.

The color of rhyolite varies and includes light tones of grays, tans, pinks, and yellows. Though of seemingly poor quality, the local rhyolites exhibit favorable knapping characteristics and also occur as raw cobbles of sufficient size for the manufacture of large implements. Site 41PS198 shows evidence of rhyolite quarrying by aboriginal inhabitants.

Riebeckite rhyolite, often referred to by the specific formation name "Paisanite," is a distinctive form of rhyolite, usually light cream or yellow in color with dark riebeckite needles (McKnight 1970:23). It occurs in river cobbles along most the Rio Grande in this area. An intrusion of riebeckite rhyolite located within the survey area is situated about one mile west of Sauceda Ranch Headquarters between an old main ranch road and a newly-cut truck loop. Investigations of this riebeckite rhyolite pluton should be conducted for possible evidence of quarrying.

Field observations and collection of arbitrary lithic material type samples from the sites indicate that the "silicified" rock (chert, chalcedonic chert) and rhyolite are the two most consistently utilized raw material types. Though broad and inclusive by definition, these two categories are helpful in the study of aboriginal lithic preferences. It is interesting to note that samples of lithic material types collected from prehistoric sites near Roma, Texas, approximately 500 miles downstream from the survey area indicate that flint (chert) and rhyolite also predominate in the utilized material types (O'Malley in press). As in the Bofecillos Mountains, the natural availability of these lithics is probably a primary factor for utilization; however, these stone types also seem to exhibit acceptable knapping characteristics which eliminate the need for exploitation of nonlocal lithic sources.

No preference toward a certain material type could be determined for grinding implements in the Bofecillos Mountains area. It appears that on-site lithic materials were utilized rather than other off-site materials (i.e., lava flow shelters usually exhibited lava flow metates). Metates and manos are formed from a variety of stone types: quartzitic sandstone, basalt, tuffs, lava flow, and river cobbles (manos). Bedrock mortars and metates are more consistently located in light-colored tuff and dark lava flows of both bedrock exposures and spall and float boulders.

DISCUSSION

The locating and recording of archeological sites is only a preliminary step to exploring the relationship of the sites to natural environmental surroundings and to other area sites. Such research constitutes a primary goal in archeology. Including the present survey, four phase one archeological reconnaissances have been conducted in the contiguous areas of the Bofecillos Mountains, the Solitario (Hudson in press), Fresno Canyon (Hudson in press), and the Colorado Canyon area (Baskin in press). It is imperative that the data from these independent reconnaissances be compiled in an attempt to collate the information into a preliminary working model as a basis for future area researchers.

The following section is a general discussion and comparison of the types of archeological sites located in the four survey areas, the availability of necessary natural resources within each area, and the indicated period of aboriginal occupation expressed through the archeological remains.

As indicated by Fig. 1, the four survey areas are adjacent to one another and a representative sample from each area has been surveyed. It should be stressed that in the surveyed areas limits are primarily arbitrary and that the Solitario represents the only geographically distinct area. The remaining areas, though variable, show fewer distinctive physical characteristics. It is believed that the following discussion will substantiate the necessity for an intensive regional study.

In overview, the four survey areas are within an arid to semiarid region. Accordingly, arid adaptive floral and faunal species are to be found except around water sources where riparian flora and aquatic fauna are able to survive. All areas have seasonally intermittent water sources and, with the exception of the Solitario, also exhibit occasional perennial sources. Although topographical and physiographical variation is noticed within each survey area and between all four areas, the terrain can be generally described as extremely rugged.

Because of the physical variation in the landscape, archeological categories (i.e. rock shelters, open sites) will be used for discussion purposes rather than the topographical and physiographical subclassifications (i.e., silt terrace site, canyon rim site, tuff shelter, etc.). Rock shelters are located within the bounds of all four areas. In such a harsh climate it is understandable why rock shelters were at a premium. From the recorded sample, it appears that the aboriginal inhabitants were not overly discriminating in selecting these rock shelters for utilization. Occupied rock shelters are found as natural cavities and overhangs in large bedrock formations and also as protected overhangs formed by the natural positioning of float boulders. The 11 rock shelter sites in the Solitario and its Shutups and the seven rock shelters in Fresno Canyon are situated in limestone, tuff, and conglomerate formations (Hudson in press), whereas the 19 rock shelters from the Bofecillos Mountains and the nine from the Colorado Canyon area are located in or under tuff and lava flow float and volcanic bedrock formations (Baskin in press:Table 1).

The elevation of the occupied shelters relative to water sources varies within and between the four survey areas. Shelters flush with or only a few meters above the drainage bottom are observed, as well as rock shelters as high as 200 meters above the drainage (Baskin in press:Table 1). Actual shelter size is also variable, but such variation is primarily determined by the geologic and/or the erosional phenomena of the specific area. Utilization of smaller rock shelters appears to be more common in the Solitario and Fresno Canyon area; however, this may be attributed to a more numerous occurrence of rock shelters in the Bofecillos Mountains and Colorado Canyon areas, which would provide a basis for selectivity by the inhabitants.

Rock shelters display similarities in general surface debris, with variation expressed mainly by numerical frequency and morphological/functional traits. Lithic debitage, lithic tools, ground stone grinding implements, bedrock mortars, and thermally altered stone constitute the majority of the surface debris. Occasional perishables (i.e., sandals, quids, sotol) and faunal remains (i.e., mussel shell, bone) are observed. Cultural features include midden deposit, dense cultural talus slopes, and pictographs. The majority of the rock shelters contain midden deposit of varying vertical depth, although several of the shelters now lack any cultural fill. The cultural talus of several rock shelters is considered to be indicative of some special activity, possibly plant processing. The talus deposit is composed of a tremendous quantity of thermally altered stone, ash, midden fill, and lithic debris. The great quantity of this refuse suggests some activity in addition to or other than fire hearths. The quantity of talus deposit does not appear to be related to the size of the associated rock shelter. Further investigation of these features may indicate that their function was similar to that of ring middens, but, because of the limited horizontal ground surface in front of most of the rock shelters, the discarded refuse was thrown downslope forming a talus rather than taking a circular shape. The majority of these cultural talus slopes are associated with rock shelters in the Bofecillos Mountains, although several are noted from the Solitario and Fresno Canyon (Hudson in press).

The observed pictographs are associated exclusively with rock shelter sites. No pictographs are reported from the Solitario (Hudson in press) and only one pictograph-bearing rock shelter is located in a minor drainage of the Colorado Canyon area (Baskin in press). Three sites displaying this aboriginal art form are located in Fresno Canyon, but the majority (seven) of pictograph sites are found in Las Burras, Auras, and Bofecillos Canyons, all within the boundaries of the Bofecillos Mountains survey area.

The geographical distribution of these pictographs is puzzling. The three westernmost major tributary canyons and another minor drainage exhibit most of the area pictographs, while the remaining art is found in the easternmost major tributary canyon, Fresno Canyon. There is a total absence of pictographs in the intervening drainages of Madera, Panther, Rancherias, and Tapado Canyons which are situated between the pictograph-bearing areas. Several representations of human figures mounted on four-legged creatures indicate a post-European/Spanish contact time period and may suggest possible association with the Polvo Site (Shackleford 1951) at Redford, Texas. Chemical analysis of pigments from pictograph sites and from any remaining wall motifs of the Polvo Site structures might validate or negate the possibility of affiliation.

The pictographs of Site 41PS114 from the Colorado Canyon area are painted solely with black pigments (Baskin in press), while the Fresno Canyon and Bofecillos Mountains area pictographs vary with the use of black, red, yellow, and white pigments (Hudson in press). Pictographs from all areas exhibit geometric, zoomorphic, and anthropomorphic designs. Mounted human figures are recorded from both the Bofecillos Mountains and Fresno Canyon sites, while handprints are found at sites from all three survey areas. The pictograph style represented at these sites is thought to be regionally isolated within the general area of the Bofecillos Mountains (Miriam A. Lowrance 1975: personal communication), but much additional work is necessary to substantiate this hypothesis.

All of the four survey areas contain open sites. Topographical location of these sites is variable, and, although terrace areas appear to be preferred, most level, relatively rock-free areas are possible site locations. Open occupation and/or lithic scatter sites comprise the major subclassification of open sites and are located in all of the survey areas. Surface debris from all open sites is generally composed of lithic debitage and tools, grinding implements, and thermally altered stone; however, a scarcity of grinding implements at sites in the Solitario is noted (Hudson in press). Midden deposit is the primary cultural feature noticed at the majority of these sites. Only one of the open sites thus far recorded in the Solitario shows any vertical depth (Hudson in press), whereas more depth of deposit is noticed among sites of the other areas.

Other subclassifications of open sites are designated by specialized surface debris and distinctive cultural features. Quarry and/or lithic procurement sites are located in all of the survey areas. Site 41PS198, within the Bofecillos Mountains area, evidences the use of surface and embedded rhyolite cobbles, while Site 41PS121, near Colorado Canyon, displays the procuring of rhyolite river cobbles and colluvial rhyolite gravels for prehistoric implement manufacture (Baskin in press). Evidence of prehistoric quarrying of light grey chert nodules in the Solitario and yellow chert in Fresno Canyon is reported by Hudson (in press).

Although within the arbitrary boundaries of the Bofecillos Mountains and the Colorado Canyon survey areas, the two recorded "wickiup" ring sites are situated along the Rio Grande within 5 km (3 miles) of one another. Constructed of small lava flow boulders and averaging 3 m in diameter, the rings of both sites are similar in appearance. Only two rings presently exist on the Colorado Canyon site, 41PS124, in contrast to the 30 to 35 rings of the southern Bofecillos Mountain site, 41PS194. The rocks of the Site 41PS194 rings are not piled as high and are more neatly positioned than are those of 41PS124, however, the latter site has been disturbed by the construction of Highway 170 which may have destroyed other associated rings. Cultural debris is similar for both sites with lithic debitage predominating. Bedrock mortars are located on Site 41PS124 and numerous manos (one hand) are found on Site 41PS194. A Perdiz-like projectile point observed on Site 41PS124 dates from 1000 to 1500 A.D. (Suhm and Jelks 1962:283) and may indicate Neo-American period chronological affiliation. A total lack of ceramics is noted at both of these sites.

Other such stone rings have been reported from Big Bend National Park (Campbell 1970:52-54), which is nearly contiguous to the eastern boundaries of the discussion areas. Twenty-two open sites have been located within the park with circular or rectanguloid rings of artifically placed stone. Campbell (1970:52-53) reports that the stones are positioned to form walls up to 3 ft thick and 3 ft high, although most are not so massive. The majority are less than 10 ft (ca. 3 meters) in diameter and some exhibit entranceways, as do several at Site 41PS194. Excavation at one of the Big Bend sites indicates a shallow fill with no cultural debris. All diagnostic projectile points from the Big Bend sites are of late Archaic styles rather than Neo-American types, as at Site 41PS124.

The "wickiup" rings described above from Big Bend National Park and the two survey areas are very similar in general appearance and may represent a distinctive style not widely evidenced in other areas, possibly indicative of a regionally isolated style within the general Big Bend area of Trans Pecos Texas. Other "wickiup rings" observed in the Trans-Pecos more appropriately coincide with the general description of Plains type "tipi rings" which have fewer rocks and involve "little or no stacking" (Campbell 1970:54), like those investigated at Ute Reservoir in northeastern New Mexico (Levine and Mobley 1976:45). Similar rings of individual stones placed side by side are reported from the general Trans-Pecos area. Examples of such rings are observed in the Amistad Reservoir area (Dibble and Prewitt 1967), within the Live Oak Archeological District in Crockett County (D.S. Dibble and J. Clark 1976: personal communication), around the Sheffield-Iraan area near the Pecos River in Crockett County (Dibble, Clark, and Gary L. Moore 1976: personal communication), and in proximity to the mouth of the Pecos River in Val Verde County (D.S. Dibble 1976: personal communication). The associated cultural debris from some of these sites contains small projectile-point styles and occasional ceramic sherds, indicating probable affiliation with Neo-American or historic aboriginal groups, in contrast to the probable Archaic association of the Big Bend National Park "wickiup" rings. At present, chronological positioning of the two "wickiup" ring sites from the survey areas would be premature; however, construction similarities with the Big Bend National Park rings tend to offer more association possibilities than does the occurrence of one Perdiz-like projectile point which may be a fortuitous occurrence on an earlier time period site. This unique stone-ring style presents an intriguing problem for future research.

With the exception of the one possible disturbed ring midden from the Colorado Canyon area, all recorded ring middens are located within the bounds of the Bofecillos Mountains survey area. Excluding Site 41PS192 which is located in the uplands, the remaining sites are situated on terraces adjacent to main drainages. The term "ring midden" is used here as a synonym for other descriptive names such as midden circles, mescal pits, sotol pits, circle mounds, cooking mounds, doughnut middens and burned rock middens which imply reference to similar-appearing surface features, but which often imply unconfirmed functional purposes. Although excavations of some ring middens indicate processing of vegetal material (Jarvis and Crawford 1974:45; Greer 1965), substantial evidence has not been obtained through the archeological record to validate assignment of this broad functional generalization to all ring middens. Ring middens have been historically and ethnographically documented (Greer 1965:50-53; Bennet and Zingg 1935:73-74, 262-262; Pennington 1963:178-179), but at least two possible functions are implied. The majority of the supporting evidence tends to lend itself to the "tuberous plant processing" hypothesis. An alternative hypothesis is presented to avoid too limited an interpretive explanation for the occurrence of these phenomena. Campbell (1970:50) suggests that some of the ring middens may be the resulting refuse of reutilized sweat baths of the type still employed by the Tarahumara of western Chihuahua (Bennet and Zingg 1935:73-74, 261-262; Pennington 1963:178-179).

Diagnostic artifacts found in association with ring middens imply utilization of this type of feature from late Archaic times, probably not much earlier than A.D. 100, until the historic era (Jarvis and Crawford 1974:42; Greer 1965:41-55). The lack of diagnostics on any of the ring middens from the Bofecillos Mountains survey area stifles any present attempts at chronological placement. Regardless of the findings resulting from previous excavations in other portions of Trans-Pecos, much testing and excavation needs to be conducted in the specific Big Bend region in order to begin compiling taxanomic and chronological data for comparisons with ring middens from other areas of the Trans-Pecos, Central Texas, and the Southwest.

In this semiarid to arid region, water is possibly the most valuable of the primary resources. Although intermittent water sources are noted in all the survey areas, the flow is determined by the amount of rainfall received. The Solitario is the only area where no perennial source was observed (Hudson in press). All other survey areas have constant water sources in the form of seeps or springs, and the southern portions of the Bofecillos and Colorado Canyon areas have the Rio Grande as an important permanent water source. Without understanding the prehistoric hydrology of the region, it is difficult to attempt speculation of site distribution in relation to active prehistoric sources. It is hypothesized, however, that during the season and the time period of prehistoric utilization, the closest water source to each site was sufficiently adequate to provide at least for basic needs.

Distinctive variation in the utilized lithic material types is evidenced from the collected material samples. The Bofecillos Mountains and the Colorado Canyon survey areas are located totally within the predominantly igneous Bofecillos Mountains and show similarities in worked-stone materials. The dominant lithic material types are silicified rocks, classified as "chert," "chalcedonic chert," and rhyolite. Except for a small amount of sedimentary chert, the majority of the worked lithics are igneous in origin but, through alteration, have silicified. Of good quality for this region, these siliceous materials exhibit good flaking characteristics but are small in size and thus are limited in their functional possibilities. Although of slightly poorer quality, the local rhyolite exhibits acceptable fracturing characteristics and provides larger flakes for manufacture of more variable implements. Rhyolite quarries are found in both of these survey areas.

Located in an area dominated by exposed Cretaceous limestone, the Solitario and Fresno Canyon survey areas exhibit prehistoric utilization of predominantly sedimentary cherts (Hudson in press). The Solitario also provides an abundance of Caballos Novaculite and Maravillas chert, but these material types exhibit poor knapping characteristics and internal fractures and impurities limit the size of both flakes and implements (Hudson in press). Although rhyolite occurs naturally in the Solitario, no evidence of its utilization for tool manufacture was observed in these two areas as it was in the Bofecillos Mountains and Colorado Canyon areas.

If the collected lithic samples are indicative of aboriginal preferences, it appears that the locally obtainable materials from each specific survey area were utilized rather than importing nonlocal material types from adjacent areas. Although aboriginal preference in all investigated areas may have been toward siliceous cherts, acceptance and use of nonsiliceous local stone types, such as rhyolite, implies that the comparative quality of nonlocal lithics was not equal to the energy expended for their exploitation and importation.

As shown, basic homogeneity is observed throughout all of the survey areas. Although the Bofecillos Mountains area exhibits more site type variability within its bounds in comparison to the other three survey areas, the general homogeneity of cultural material and types of sites remains apparent. Such similarities can be partly attributed to a basic adaptation to an arid to semiarid environment such as is represented in the Southwest by the Desert Culture (Martin and Plog 1973:69-80).

The previous area survey reports (Hudson in press; Baskin in press) have not attempted to assign area sites to an established chronology. This is justified in view of the small sample of observed diagnostic artifacts. In comparison with sites upstream along the Rio Grande (Shackleford 1951, 1955; Lynn and Baskin 1975) which indicate habitation by horticultural/ceramic-making Neo-American groups, the sites found in the four survey areas seem representative of aboriginal groups subsisting on a hunting and gathering economy. Such a subsistence pattern is generally associated with the Archaic developmental stage; however, the continuance of a successful lifeway through sequential time periods, with only minor stylistic variations, is very probable in such a restrictive environment.

Although the number of chronologically diagnostic artifacts are few, evidence satisfactorily indicates that area sites have been occupied during the Archaic and Neo-American stages and into historic times. With the exception of the Colorado Canyon survey area, Langtry-like and other Archaic dart points have been observed on sites in all of the other survey areas. Although no temporal placement can be assigned, other indications of an Archaic-like lifeway are evidenced in the four areas. The generally small areal extent of sites tends to indicate probable utilization by small bands or groups of kinship or clan-related individuals. The spacial density of sites, and the variability in vertical density of midden deposits and numerical frequency of artifacts, may represent seasonal reutilization of both specific site areas and the general region. The observance of functionally diagnostic tools, ring middens, and quarry areas may offer further indications of an Archaic-like hunting and gathering subsistence. The total absence of ceramics in the areas may also contribute negative evidence for an Archaic occupation.

The "wickiup" rings of the area are similar in appearance to those observed in the Big Bend National Park at which late Archaic style projectile points were observed (Campbell 1970:54). Although the diagnostic projectile point type found in association with Site 41PS124 is a Neo-American Perdiz-like point, its occurrence may be fortuitous, whereas the association of the late Archaic points is not. Thus, the present temporal placement for the "wickiup" rings indicates a broad time span which may range from late Archaic to historic times. Ring middens have also been dated from the late Archaic into the historic period (Campbell 1970:50), but without diagnostic artifacts or radiocarbon dating cannot be used as chronological indicators except for very broad time periods.

The Neo-American stage is evidenced in all four survey areas either by the occurrence of small arrowpoint styles (i.e., Perdiz-like) or by pictographs depicting mounted human figures which indicate a post-European contact period. Considering the proximity of the four survey areas to the horticultural/ceramic-bearing Polvo Site, it is unusual that no ceramics, even single isolated sherds, were observed in these areas which may have provided outlying resource exploitation areas for the large Polvo Site. The Rio Grande terrace sites of the Colorado Canyon area present the greatest puzzlement because, except for the total lack of ceramics, they exhibit similarities in topographic location and cultural debris with the ceramic-bearing Rio Grande terrace sites to the northwest which were occupied by Neo-American horticultural/ceramicists (Shackleford 1951, 1955; Lynn and Baskin 1975).

A synthesis of the above temporal indicators expresses the aboriginal utilization of this region from the Archaic through the Neo-American stage and possibly into the historic aboriginal period. The homogeneity of the surface debris and cultural materials poses the possibility of the continuance of a non-specialized Archaic-like hunting and gathering mode of subsistence which persisted through the Archaic and possibly into the late historic period.

RECOMMENDATIONS

The preliminary archeological reconnaissances conducted by the Natural Areas Survey Project in the four contiguous areas—Bofecillos Mountains, the Solitario, Fresno Canyon, and Colorado Canyon—have revealed this general region to be an important, possibly transitional zone, in Trans-Pecos Texas archeology. The following recommendations are presented as a guideline for any future archeological program for intensive regional research:

1. Intensive, systematic surveying of all previously investigated areas, providing total area coverage for comparative purposes in determining the validity of predictions based on preliminary sample area surveys conducted during the previous four reconnaissances.
2. Initiation of a program for controlled, systematic surface collections from sites and intensive analysis of the collected materials.
3. Subsurface testing of selected sites for determination of data recovery potentials.
4. An intensive excavation program for selected sites, assuring total data recovery and analysis

of cultural materials. Excavations should not proceed without assurance of funding for studies such as lithic analyses, faunal identification, radiocarbon dating, paleobotanical studies, pollen analysis, and other pertinent studies.

In addition to these general recommendations, several specific problems have emerged in this area which deserve continued research:

1. Research of area pictographs is necessary because of the fragile and nonrenewable nature of these resources. Such studies should include:
   A. Mapped plottings of locations and detailed descriptions of the archeological sites associated with the pictographs.
   B. Scale drawings of each pictograph (in sequential order if associated with more than one other pictograph).
   C. Scale photographs, both color and black and white, of the general site area, an overview of all pictographs, and photographs of individual pictograph designs.
   D. Research and surveying of adjacent area pictographs for comparative purposes in attempting to distinguish stylistic attributes which may be used as indicators of temporal placement, cultural affiliation, etc.
2. Special investigations of the outlying areas around the Polvo Site near Redford, Texas, to determine the precise extent of ceramic-bearing sites in this area. Further research should be conducted upstream from Redford to determine if a noticeable diminishing density of the ceramic sites can be calculated and, if so, what factors may have contributed to this phenomenon.
3. A literature review and field inventory of stone-stacked "wickiup" rings to determine if the similarly constructed rings of the present survey areas and Big Bend National Park are truly a regionally isolated style. Further research should attempt to determine chronological placement, functional attributes, and cultural affiliation of these rings.
4. Investigation of two specific areas, Rancherias Dome and a reibeckite rhyolite pluton, which may represent possible prehistoric lithic quarries.

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TABLE 2

LIST OF POSSIBLE ECONOMICALLY VALUABLE FLORA

Although the mode of subsistence employed by aboriginal populations of this general region is only speculative, a list of economically important flora has been compiled with major assistance by Mary Butterwick, Natural Areas Survey Project botanist, in order to stress the many possibilities for utilization of the indigenous floral resources within this semiarid environment. The flora listed in the following table are species observed within the surveyed areas which have edible, medicinal, and technological propensities for economic value. The importance of such flora to aboriginal cultures has been documented by previous ethnobotanical studies. Though none of these studies were conducted in this specific region and though variation may be noted in the degree of dependence upon, and specific methods of gathering, processing, and subsequent utilization of these wild economic flora, the study of subsistence systems of aboriginal groups inhabiting other semiarid to arid geographical areas which support similar biotic communities may enable the realization of a possible mode of subsistence for the aboriginal inhabitants of this region.

No specific information is presented in Table 2 concerning gathering and/or processing methods or specific uses of the various flora; however, the following references are cited for those interested in pursuing intensive research: Balls 1970; Bell and Casteller 1973, 1941; Castetter 1935; Castetter and Bell 1937, 1942, 1951; Casterrer, Bell, and Grove 1938; Casteller and Opler 1936-1937; Castetter and Underhill 1935; Cook 1939; Elmore 1944; Reagan 1928; Russell 1908; Standley 1911; Stevenson 1915; Swank 1932; Whiting 1939; Basehart 1973; Burloge 1968; Bohrer 1973; Opler 1941, 1969; Uphof 1968; Applegate and Hanselka unpublished manuscript.

Adiantum capillis-veneris (maiden-hair fern)
Ephedra aspera (Morman tea)
Ephedra antisyphititica
Ephedra trifarca
Typha latifalia (Cat tail)
Arundo donax (Carrizo, giant reed)
Echinochloa colunum (Jungle rice)
Sporobolus airoides (Alkali sacaton)
Sporobolus contractus (Spike dropseed)
Yucca torreyi (Spanish dagger)
Yucca thompsoniana (Thompson yucca)
Agave lecheguilla (Lecheguilla)
Salix gooddingii (Southwestern black willow)
Julans microcarpa (Little walnut)
Celtis pallida (Spiny hackberry)
Celtis reticulata (Metleaf hackberry)
Parietaria obtusa (Pellitory)
Eriogonum jamesii (James wild buckwheat)
Eriogonum rotendifolium (Round leaf wild buckwheat)
Selaginella lepidophylla (Resurrection plant)
Atriplex canescens (Four-wing saltbush)
Chenopodium leptophyllum (Slimleaf goosefoot)
Salsola kali (Russian thistle)
Amaranthus torreyi (Amaranth)
Rivina humilis (Pigeon berry)
Portulaca mundula (Shaggy portulaca)
Talinum angustissimum (Flame flower)
Clematis alpina (Alpine clematis)
Clematic drummondii (Texas virgin bower)
Hepidium virginicum (Pepperwood)
Rorippa nasturtium-aquaticum (Watercress)
Lesquerella fendleri (Bladderpod)
Sioymbrium linearifolium
Fallugia paradoxa (Apacheplume)
Acacia greggii (Catclaw acacia)
Sophora secundiflora (Mescal bean)
Prosopis glandulosa (Mesquite)
Krameria grayi (Grays ratany)
Porlieria angustifolia (Guayacan)
Larrea tridentata (Creosote)
Croton dioicus (Croton)
Euphorbia albomarginata (White margin euphorbia)
Jatropha dioica (Congre de drago)
Rhus toxicodendron (Poison ivy)
Rhus virens (Evergreen sumac)
Ungnadia opeciosa (Mexican buckeye)
Vitis anrzonica (Canyon grape)
Sphaeralcea angustifolia (Marrowleaf globemallow)
Forquieria splendens (Ocotillo)
Mentzelia oligosperma (Chicken-thief)
Echinocereus stramineus (Spinemound)
Echinocereus triglochidatus (Claret cup)
Echinocereus dasyacanthus (Pitaya)
Opuntia imbricata (Cholla)
Opuntia engelnannii (Engelmann prickly pear)
Gaura coccinea (Gaura)
Diospyras texana (Persimmon)
Heliotropium currassavicum L. (Salt heliotrope)
Hedeoma drummondii (Drummond hedeoma)
Datura wrightii (Sacred datura)
Vicotiana trigonophylla (Desert tobacco)
Penstemon lavardii (Havard penstemon)

Penstemon buccarifolius (Charis leaf penstemon)
Chilopis linearis (Desert willow)
Tecoma stans (Trumpet flower)
Lobelia cardinalis (Cardinal flower)
Cephalonthus occidentalis (Buttonbush or honeyballs)
Buccharis glutinosa (Seep willow)
Hymenoclea monogyra (Burrobrush)
Helianthus annus (Sunflower)
Sonchus asper (Prickly sowthistle)
Artemisia ludoviciana (Sagewort)
Porophyllum scoparium (Poreleaf)
Senecio longilobus (Threadleaf groundsel)
Pectio papposa (Many bristle pectis)
Conyza canadensio (Conyza)
Sasylirion sp. (Sotol)
Populus sp. (Cottonwood)
Nicotiana trigonophylla (Desert tobacco)
Canadalia canescens (Lotebush)
(Chino grass)
(Aristida grass)
(Stipa needle grass)
Berberis trifoliolata (Agarita)

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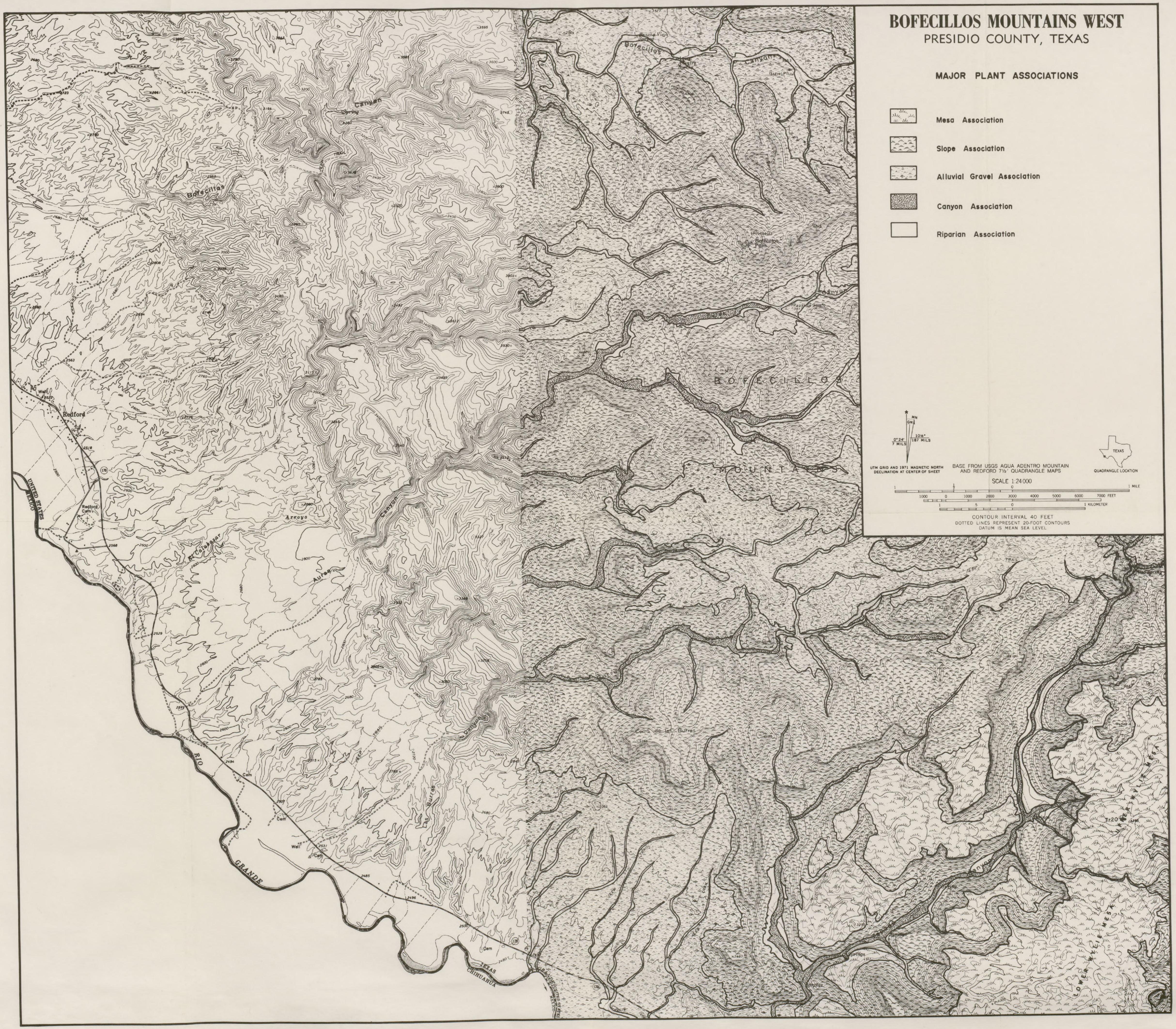
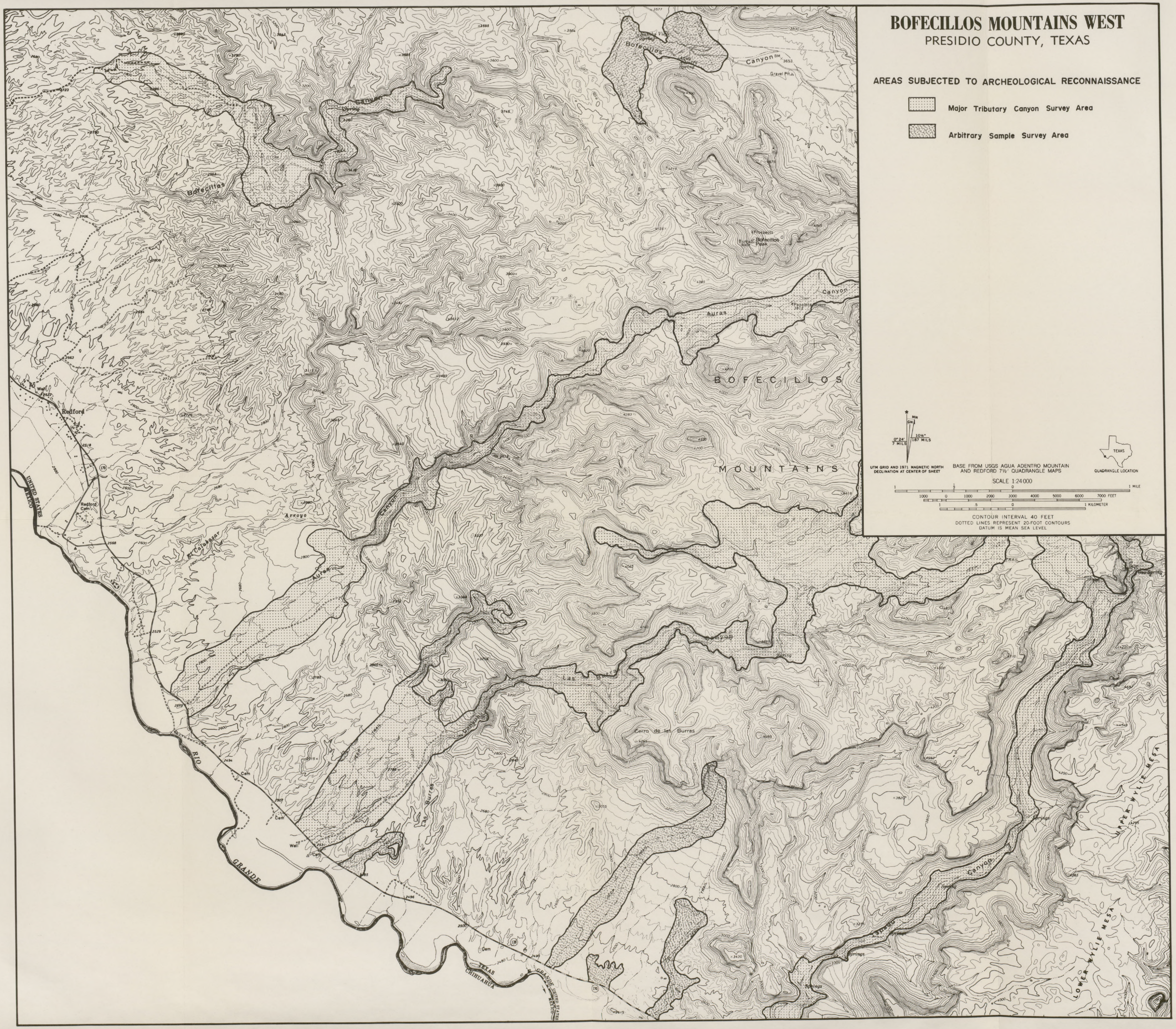
BOFECILLOS MOUNTAINS

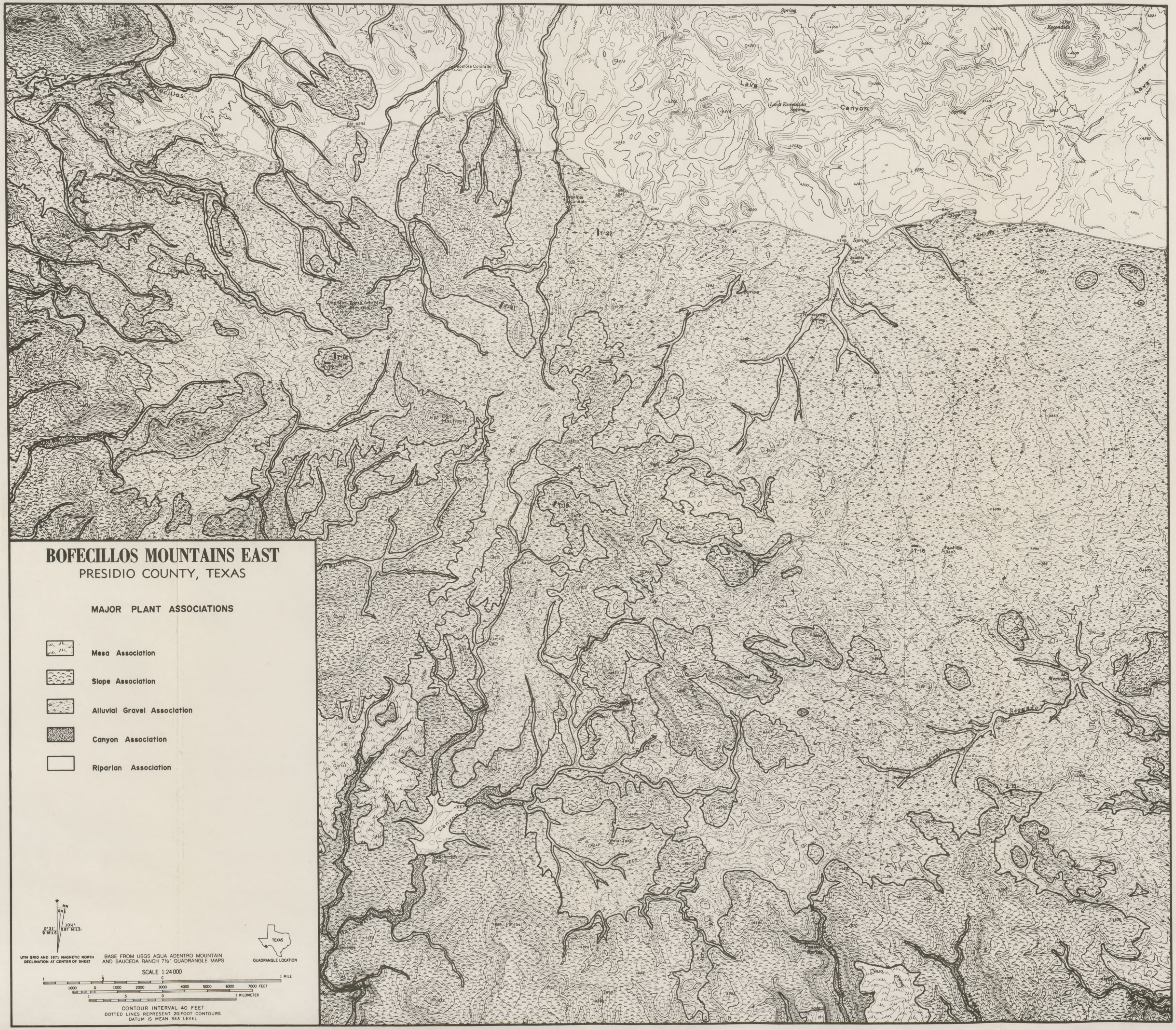
A NATURAL AREA SURVEY
NO. 12

Lyndon B. Johnson School of Public Affairs
The University of Texas at Austin
1976

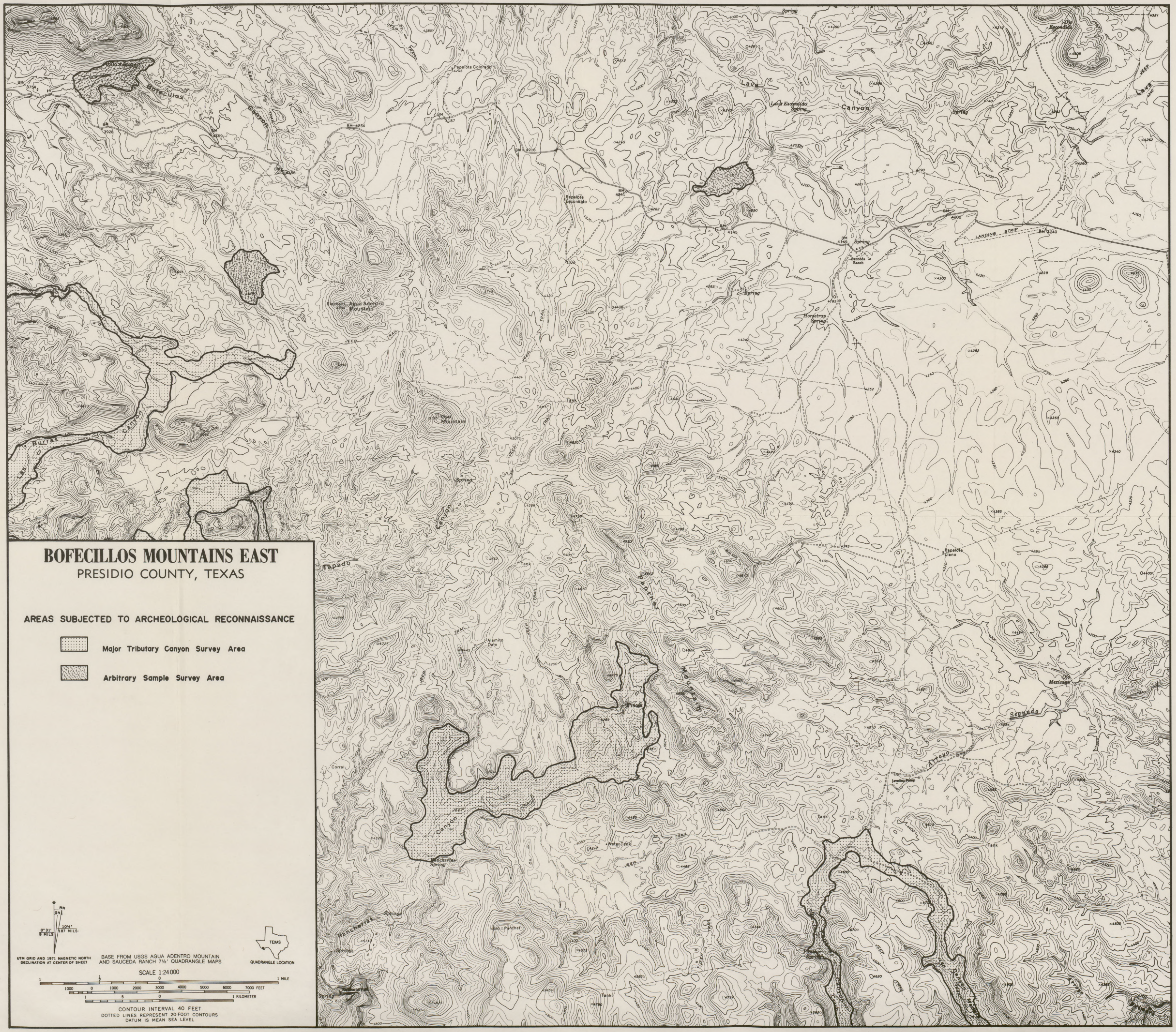

BOFECILLOS MOUNTAINS WEST
PRESIDIO COUNTY, TEXAS
MAJOR PLANT ASSOCIATIONS
Mesa Association
Slope Association
Alluvial Gravel Association
Canyon Association
Riparian Association
UTM GRID AND 1971 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
BASE FROM USGS AGUA ADENTRO MOUNTAIN AND REDFORD 7½′ QUADRANGLE MAPS
TEXAS
QUADRANGLE LOCATION
SCALE 1:24 000
1 MILE
7000 FEET
1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
BOFECILLOS
MOUNTAINS
Redford
RIO GRANDE
TEXAS
CHIHUAHUA
UNITED STATES
MEXICO



BOFECILLOS MOUNTAINS WEST
PRESIDIO COUNTY, TEXAS
AREAS SUBJECTED TO ARCHEOLOGICAL RECONNAISSANCE
Major Tributary Canyon Survey Area
Arbitrary Sample Survey Area
UTM GRID AND 1971 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
BASE FROM USGS AGUA ADENTRO MOUNTAIN AND REDFORD 7½′ QUADRANGLE MAPS
TEXAS
QUADRANGLE LOCATION
SCALE 1:24000
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
BOFECILLOS
MOUNTAINS
Redford
RIO GRANDE
Cerro de las Burras
LOWER WYLIE MESA
UPPER WYLIE MESA



BOFECILLOS MOUNTAINS EAST
PRESIDIO COUNTY, TEXAS
MAJOR PLANT ASSOCIATIONS
Mesa Association
Slope Association
Alluvial Gravel Association
Canyon Association
Riparian Association
Lava Canyon
Spring
MN
GN
0° 31′
9 MILS
10½°
187 MILS
UTM GRID AND 1971 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET
BASE FROM USGS AGUA ADENTRO MOUNTAIN
AND SAUCEDA RANCH 7½′ QUADRANGLE MAPS
TEXAS
QUADRANGLE LOCATION
SCALE 1:24000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL



BOFECILLOS MOUNTAINS EAST
PRESIDIO COUNTY, TEXAS
AREAS SUBJECTED TO ARCHEOLOGICAL RECONNAISSANCE
Major Tributary Canyon Survey Area
Arbitrary Sample Survey Area
UTM GRID AND 1971 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
BASE FROM USGS AGUA ADENTRO MOUNTAIN AND SAUCEDA RANCH 7½′ QUADRANGLE MAPS
TEXAS
QUADRANGLE LOCATION
SCALE 1:24 000
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
Lava Canyon
Bofecillos Canyon
Agua Adentro Mountain
Ojo Mountain
Tapado Canyon
Rancherias Spring
Horsetrap Spring
Landing Strip
Spring
Tank